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JOURNAL
IRRIGATION AND DRAINAGE DIVISION
Proceedings of the American Society of Civil Engineers

COST ALLOCATION FOR MULTI-PURPOSE WATER PROJECTS

N. B. Bennett, Jr.,* A.M. ASCE
(Proc. Paper 961)

SYNOPSIS

The recently adopted Separable Costs-Remaining Benefits method of cost allocation has not been used long enough to achieve precise understanding of its procedural details and basic concepts. This paper points to the method's dependence on benefits and alternate costs, and the meanings attached to single-purpose alternate costs, specific and separable costs, joint costs, and remaining project costs. These concepts are discussed in relation to each other and to broad principles of cost allocation, use of project works, project formulation, and legislative history.

Need for Allocations of Costs

Government agencies in the water development field find it necessary to assign or allocate costs of multiple-purpose structures, such as a dam, among the functions to be served by that structure. This operation becomes necessary by reason of two facts:

1) The utilization of one structure to provide services of different natures; and
2) The requirements of Federal laws that make some services reimbursable, others non-reimbursable, some interest-bearing and others non-interest bearing.

Allocation is then the process of assigning to each function in a multiple-purpose project an equitable share of the cost of the project. Within each such project there will generally be costs of a specific nature, i.e. readily identified with a single function; and those of a joint nature, i.e. related to two or more functions. It is with the distribution or allocation of the latter that we are principally concerned here.

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Methods of Cost Allocations

There are many methods of allocating costs, and any one method, or a combination of several, might be applicable in a particular situation. This paper will not cover all methods, but rather will set forth some of the basic concepts which should govern the preferable methods. In March 1954, the three Federal agencies dealing principally with multiple-purpose projects, the Federal Power Commission, Corps of Engineers, and Department of the Interior, agreed on the use of three methods. Those three were the Separable Costs-Remaining Benefits, Alternative Justifiable Expenditure, and Use of Facilities, listed in order of preference.

The Separable Costs-Remaining Benefits method is one in which each purpose is assigned its separable cost plus a share of joint costs proportionate to the remainders found by deducting the separable cost of each purpose from the lesser of the benefits or the alternate cost for that purpose (See Tables I and II).

The Alternative Justifiable Expenditure method is one in which each purpose is assigned its specific cost plus a share of joint costs proportionate to the remainders found by deducting the specific cost of each purpose from the lesser of the benefits or the alternate cost for that purpose (See Table I).

The Use of Facilities method is one in which each purpose is assigned its specific cost or its separable cost, plus a share of joint costs proportionate to the use of facilities in terms of comparable measures such as water releases, reservoir capacity, power capacity, or consumption of energy.

The Use of Facilities method, however, has only limited application such as in dividing the cost of a canal between municipal water and irrigation water on a capacity basis. It is useful, then, in making sub-allocations on the simple basis of a proportionate use of a given facility as measured in physical terms.

The Alternative Justifiable Expenditure method is, no doubt, the better known of the other two, and has only one significant difference from the Separable Costs-Remaining Benefits method; that is, with the latter separable costs are used rather than specific costs as in the A.J.E. method. This distinction will be discussed later.

Each of these two methods has seven major steps which are illustrated on Table I. Many of the problems which will be discussed subsequently dealing with the selection of alternatives are common to both methods.

Principles of Cost Allocation

The use of one structure to provide more than one service allows the services to be provided at less cost than the total cost of separate structures for each service. The incremental cost of providing each function as an addition to the other functions of the combined structure should be less than the cost of the most economical single-purpose alternative means of producing similar benefits for that junction. This being so, a basic principle of cost allocation is that the saving derived through use of the combined structure for numerous functions should be shared equitably by all functions. There are certain benefit-cost relationships which must be recognized, such as that no function be assigned costs in excess of its benefits or be supported by benefits attributable to another purpose, and no function be assigned costs greater than the cost of an alternative single-purpose project. The allocation must, of course, be consistent also with existing laws, treaties and compacts affecting the project plan.

There is general agreement that the following broad principles are applicable:

1) Each purpose should share equitably in the savings resulting from multiple-purpose construction, within the limits of maximum and minimum allocations.
2) The minimum allocation to each purpose is its specific or its separable cost, depending on the method of allocation.
3) The maximum allocation to each purpose is its benefits or alternative single-purpose cost, whichever is less.
4) Joint costs should be apportioned without regard to the ability of any particular purpose to repay its costs.
5) Legal priorities for the use of water and existing laws, treaties, and compacts must be recognized.

Inherent Weaknesses

Any allocation method which uses benefits at any stage is subject to the question of the validity of the benefits. The term benefits may be defined as the estimated value of the services or products produced by the various functions of the project. As will be noted from Table I, benefits are used in both methods as a rein on alternate costs, as a measurement of the maximum allocation, and as the basis of proportioning joint costs. They are, therefore, under certain conditions, critical in the determinations. Theoretically, an equitable apportionment will result only if the benefits are equally valid among themselves. In other words power benefits, or municipal and industrial water benefits, should be computed with the same validity as irrigation and flood control benefits. It can be questioned whether this is currently being done. Power and municipal water supply benefits are usually computed as functions of alternative costs. Irrigation benefits are measured as increased net income, while flood control is measured as savings in damages.

In addition there may be intangible benefits on which monetary values cannot be placed, yet they are real benefits not entering into the allocation process.

The other major weakness is in the adequacy of the basic data used in estimating alternatives for the single purpose. Many times that alternative will be a different dam site for which little if any basic data are available. The cost estimate is not likely to be of the same degree of validity as that used for the project.

These are matters of concern for aspects of project development in addition to cost allocations. They can affect project formulation and justification. They do not, however, affect the application of the cost allocation method.

Basic Concepts

Uniform application of the Separable Costs-Remaining Benefits method requires acceptance and adoption of basic concepts covering alternative single-purpose costs, specific costs, separable costs, and perhaps remaining project costs. Adoption of a particular method does not by itself guarantee uniform procedures and results. Simply to say that one will use separable costs is not the answer as those costs are subject to acceptable definition and the application thereto of guiding concepts. Methodology is still being explored to

clarify the relationships between generally accepted concepts and the desirable degree of refinement.

I would like, therefore, to set forth, under the remaining topics in this paper, some of the possible basic concepts affecting the Separable Costs-Remaining Benefits Method.

Example of an Allocation

To make for better understanding of the material to follow, I have prepared Table II. That table shows in a very simplified manner application of the major steps involved in applying the Separable Costs-Remaining method. Table I states what those steps are. For purposes of ease of understanding, and because they do not affect the points raised hereinafter, I have not included such things as interest during construction, addition of taxes foregone, and operation and maintenance costs.

Selection of the Single-Purpose Alternative

In the interest of providing service to each project purpose at least cost, all practical alternative means of single-purpose development in the project area should be considered. The most economical alternative means of providing benefits equivalent to those provided by the selected project should be used in project formulation and in cost allocation. That alternative does not have to be located at the multiple-purpose project site, and it may be entirely different in physical plan, as when a steam-electric development is the most economical alternative for a hydroelectric plant. Because of the scarcity of available sites, construction of a single-purpose dam may preclude use of the same site to serve other purposes for which that site is necessary or most suitable. This practical difficulty does not prevent the use of the site for considering an alternative for calculating single-purpose costs for allocation purposes. The alternative should be real in the sense that it can be built, and if built would produce the equivalent benefits. The single-purpose alternative need not have benefits in excess of its costs, for it may be unjustifiable as a separate project. In such cases the benefits rather than the alternative single-purpose costs are used as upper limits in cost allocation. The alternative single-purpose costs properly represent one limit on costs which may be included in project plans and allocated to a purpose; the other upper limit being the evaluation of benefits.

As just stated, it is not required that the single-purpose alternative be justified. Little is to be gained by requiring such justification. In many cases a justifiable alternative of any magnitude does not exist. If the alternative must produce benefits equivalent to those of the selected project, the chances of justification are even less. Such a hypothetical requirement then would become rather meaningless because in many cases there would be no alternative. In such cases it would likely be necessary to rely solely on benefits as the measure of the maximum allocation. It would seem that the most to be gained by requiring justification of the alternative is the refinement of the costs of that alternative which would likely result because of the efforts made to find justifiable alternatives.

Specific Costs

The readily determinable costs of facilities which are clearly for one purpose only should be allocated specifically and wholly to that purpose. Examples are powerplants, transmission lines, irrigation canals. The costs of facilities that serve a single purpose are called specific costs, and represent the minimum allocation in the alternative justifiable expenditure method. At times there will be space in a jointly used reservoir which is assigned exclusively to a single purpose. An example is the inviolate flood control space in many reservoirs. The specific cost of providing such space is not readily determinable because it occurs at the top of the reservoir. The cost of adding the increment can be determined by subtraction of the cost of the structure without the space from that with the space, but this encroaches upon determination of separable costs. By definition specific costs are reconcilable with engineering cost estimates which list the costs of separate physical features such as dams, canals, tunnels, penstocks, powerplants, and electric transmission systems. The remainder of multiple-purpose project costs would be those items in engineering cost estimates representing the total cost of jointly used physical features. An alternative approach would carry the segregation of specific costs to the point where it encroaches upon the apportionment of joint costs, and does not use the cost of a physical feature as the unit of calculation. For example, the specific cost of a powerplant or penstock embedded in a dam may be listed as the cost of the powerplant or penstock adjusted to reflect the alternate cost of constructing a dam without the embedded features. This type of adjustment may greatly modify the specific cost and in some cases might eliminate it. Such adjustments may be worth the effort where costs of major magnitude are involved, but they apply to separable costs rather than to specific costs, as defined in the recent interagency agreement.

Separable Costs

Separable costs include specific costs plus that portion of joint costs which is traceable solely and clearly to the inclusion of a single purpose in the multiple-purpose project. The concept of separable costs is an extension of the basic idea of direct assignment of specific costs. The separable cost is the minimum allocation to a function when using the Separable Costs-Remaining Benefits method. It is quite possible to find that no portion of the joint cost is solely traceable to a particular purpose. Separable costs for any purpose may be zero, or specific costs only, or specific plus some portion of joint costs. When separable costs for all purposes consist of specific costs or are zero, the Separable Costs-Remaining Benefits method is identical with the Alternative Justifiable Expenditure method in computation and results, although more time, effort, and money may have been consumed in exploratory studies of possible separable costs.

Identification of Separable Costs

Although separable costs might conceivably be obtained by addition of component elements, in practice and by definition they are obtained by subtraction. The separable cost for each purpose is defined as the difference between the cost of the multiple-purpose project and the cost of the same

project with the purpose omitted. To avoid favoring one purpose over another, each purpose should be treated as if it were the last increment to a diminshed project serving all other multiple purposes. This calculation is intended to identify the added costs of increased size of structures, changes in design, or other factors necessary to add the purpose to the project. A series of cost estimates must be prepared, representing the multiple-purpose project without each purpose. A clear distinction should be maintained between the concepts underlying these estimates, which may be called remaining project costs, and the concepts of alternative single-purpose costs previously discussed.

Remaining Project Costs

If the project has been properly formulated the remaining project cost will be justifiable by an excess of benefits over its costs. For purposes of cost allocation, however, the remaining costs need not be justified. Furthermore, for allocation purpose it does not need to be the most economical source of providing multiple-purpose benefits to the remaining project functions. To find and to use the most economical alternative in this instance might disperse the functions to other sites and substitute other types of features, such as a steam-electric rather than a hydroelectric plant. Such a dispersal or substitution would not reveal increments of separable cost by identifying the remaining portion of the multiple-purpose project; instead, it would present a comparison of the multiple-purpose project with a competitive plan of different nature and location. Such a comparison is brought into the cost allocation by the alternative single-purpose costs. The cost allocation process should not be complicated by introducing the additional category of alternative multiple-purpose costs.

Another approach to remaining project costs would be to seek the most economical plan regardless of location or type of physical facilities. Still another approach would be based upon the most economical plan for each combination of purposes at the multiple-purpose site. To follow these concepts appears to lead to inconsistencies. Take as an example the omission of irrigation from a project including hydroelectric power. If the water required for irrigation depletions were used for power, the most economical source of power benefits equal to those obtained from the multiple-purpose project might be a less expensive powerplant. In this case, the reduction in specific power costs (reflected in the cost of certain generating units) would become part of the separable cost of irrigation, which is obviously illogical. It therefore appears necessary to leave specific costs unchanged in the remaining project, and to reject the definition based on the most economical plan at the multiple-purpose site.

In the example cited, remaining project costs might also be based upon an unchanged powerplant but with reservoir storage reduced to keep power benefits constant. It might be based upon an unchanged powerplant with reservoir capacity reduced only by the amount of irrigation storage, possibly resulting in power benefits greater than those obtained from the multiple-purpose project. The choice will depend in part upon storage capacity required to avoid interference with other project purposes. Use for power of the water required for irrigation depletions, in addition to omission of irrigation storage capacity, might drastically reduce the size of the reservoir in the remaining project. The reduction might well go to the point where the separable cost of

irrigation exceeds the alternative single-purpose cost of irrigation. This would establish the minimum allocation at a greater cost than the maximum allocation, which is also illogical. Cases will arise where greater benefits to some purpose are unavoidable if basic concepts of allocation are to be preserved. The remaining project, however, should provide benefits to each remaining purpose at least equal to those obtained from the multiple-purpose project.

Joint Use of Reservoir Capacity

As previously noted the cost of exclusive space assigned to a single project purpose should be omitted from the remaining project in determining the separable cost of that purpose. The treatment of seasonally exclusive space is less clear, as in the case of seasonal flood control space which at other times of the year serves other purposes. To avoid interference with these other purposes, in the determination of separable flood control costs the seasonal flood control space should be treated as an inseparable joint cost included wholly in the remaining project. As another example, if all water releases for navigation are also used for power generation, the omission of navigation would not allow a reduction in reservoir capacity, and the separable cost of navigation would be limited to specific costs. A further illustration is the case where one purpose, such as irrigation, is served by pumping from the reservoir, so that change of reservoir capacity by omitting another function would increase pump lifts and interfere with irrigation operations and benefits. Truly separable costs include those portions of jointly used works which can be omitted without interfering with other junctions; if interference is caused, that segment is an inseparable joint cost.

Emphasis upon Separable Costs

Some aspects of the Separable Costs-Remaining Benefits method are relatively new, and procedures for the derivation of separable costs are still being explored. Major problems appear to involve confusion and overlapping of concepts, and the degree of refinement that is worthwhile. An extreme degree of refinement is involved when attempts are made to assign the maximum amount of joint costs to the category of separable costs. By intensive effort, if none of the project purposes have separable costs limited to specific costs or zero, it might be possible to obtain a total of separable costs for all purposes amounting to more than the multiple-purpose project costs. Separable cost is the thing being sought and emphasis should be there, rather than upon remaining project cost. The latter is only a statistical residue in the derivation of separable costs.

Project Formulation and Legislative History

The Separable Costs-Remaining Benefits method may not yield equitable results if it is applied arbitrarily to a project where the scale of development for each purpose was determined upon other concepts, such as maximum use of a favorable site. The method may also have limited usefulness if it is applied retroactively to a project governed by a legislative background and justifying reports which base project authorization on other cost allocations, such as fixed proportionate uses of project works. In such cases the cost

allocation will need to recognize the criteria employed in formulating, authorizing, and constructing the project.

ACKNOWLEDGMENTS

I take this opportunity to acknowledge and to extend my appreciation and thanks for the help of many people in preparing this paper. Those people have done much to improve and identify the basic concepts which should control allocations. I wish specifically to mention Ira A. Watson and John D. Abrahamson both of whom contributed materially to this paper, and to James C. Bradley and George E. Tomlinson who were kind enough to review the draft and thus aid in its final preparation.

TABLE I

Brief Description of Steps Involved in Methods of Cost Allocation

Separable Costs-Remaining Benefits Method	Alternative Justifiable Expenditure Method
(1) The benefits of each purpose are estimated. (2) The alternative costs of single-purpose projects to obtain the same benefits are estimated. (3) The separable cost of each purpose is estimated. (4) The separable cost of each purpose in the multiple-purpose project is deducted from the lesser of each purpose's benefits or alternative cost. The lesser figure is used since alternative cost is used in this method only if it represents a justifiable expenditure, that is, if it does not exceed the benefits. (5) From total cost of project deduct all separable costs to determine residual costs. (6) Residual costs, designated as joint costs in this method, are distributed in direct proportion to the remainders found in step 4. (7) To determine the cost allocated to each purpose, add the separable and distributed costs for each purpose and, in the case of power, subtract from that sum the amount of taxes foregone which was used in computing power costs under steps 2 and 3 above.	(1) The benefits of each purpose are estimated. (2) The alternative costs of single-purpose projects to obtain the same benefits are estimated. (3) The specific cost of each purpose is determined. (4) The specific cost of each purpose in the multiple-purpose project is deducted from the lesser of that purpose's benefits or alternative cost. The lesser figure is used since alternative cost is used in this method only if it represents a justifiable expenditure, that is, if it does not exceed the benefits. (5) From total cost of project deduct all specific costs to determine joint costs. (6) Joint costs of the multiple-purpose project are distributed among purposes in direct proportion to the remainders found in step 4. (7) Allocation of project cost is determined in the same manner as under the separable costs-remaining benefits method.

TABLE II

SIMPLIFIED ILLUSTRATION
OF APPLICATION OF
SEPARABLE COST-REMAINING BENEFITS METHOD

(Thousands of Dollars)

Item	Project Purposes			
	Flood Control	Irrigation	Power	Total
1. Benefits	8,000	23,000	35,000	
2. Alternative single-purpose cost	10,000	27,000	30,000	
A. Lesser of (1) or (2)	8,000	23,000	30,000	
3. Separable costs	0	8,000	29,000	37,000
4. Remaining Benefits (2A-3)	8,000	15,000	1,000	24,000
Percentage of total	33	62	5	100
5. Unallocated Joint cost (Project Cost-3)				19,000
6. Allocated joint cost	6,300	11,800	900	19,000
7. Total allocation (6 + 3)	6,300	19,800	29,900	56,000

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DESIGN OF MAJOR DRAINAGE CANALS

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(Proc. Paper 962)

ABSTRACT

The economical utilization of many relatively low areas depends on the efficiency with which drainage systems can be designed to remove excess floodwaters. This paper is concerned chiefly with areas in which the only practical measure for the control of floods is by improving and enlarging existing outlets or by diverting excess water to some alternative, more economical, outlet. In the design of drainage facilities to serve those areas, the most economical solution can be accomplished only by careful consideration of all factors to make best use of the available slope. In areas where ground slope is low, a combined canal and pumping station system is often the best solution. Such a system should be designed to remove excess floodwaters at the lowest costs, with all costs reduced to an annual basis. The planning and design of many of the major drainage works of the Central and Southern Florida Flood Control Project have been based on providing flood relief by improvement and enlargement of major canal systems. In many areas on that project, because of a lack of slope, satisfactory drainage must be based on a pumped system. This paper has been based on experience of the writer in planning required for that project. Design work on Hillsboro Canal illustrates the procedure used to develop the most economical solution and is the basis for this discussion.

INTRODUCTION

General Discussion of the Problem

While there are many canal designs which from a theoretical standpoint would provide satisfactory drainage, the most economical solution can be arrived at only after consideration of all basic factors, theoretical and practical.

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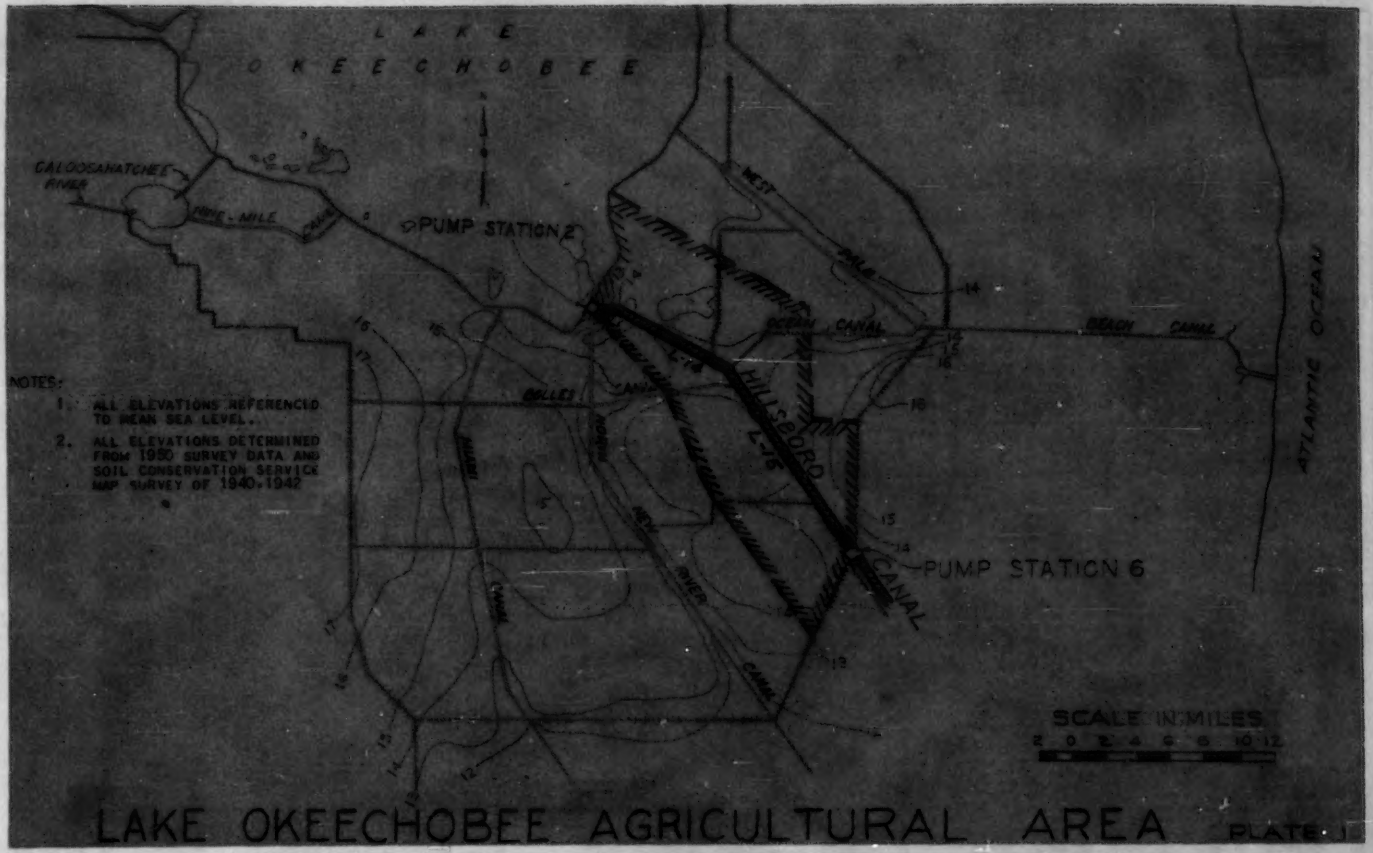
As will be developed in the discussion which follows, the practical problems of canal excavation and maintenance are fully as important in determining proper canal design as the theoretical determination of the carrying capacity. The design problem can be divided into three interrelated problems: First, design of the proper section to provide the required cross section over the life of the canal at minimum cost; second, design of the water-surface profile to effectively utilize the available slope to convey the design discharge; and third, where insufficient slope requires pumping, the proper balance between design of the canal cross section, the water-surface profile, and the design of the pumping installation.

The problem is most easily approached as a trial-and-error solution since many of the variables which have a material effect on the design cannot be reduced to a readily usable mathematical relation. Typical variables of this nature are ground elevations along the proposed canal, character of soil through which the canal will be excavated, character of the excavation equipment available in the area, distribution of inflow to the canal, and probable cost of fuel required by the pumping station. However, general relations for portions of the design problem can be developed and may be applied to other canals in the same area which are similar in character.

Description of Hillsboro Canal

The procedure has been applied to design of the enlargement of Hillsboro Canal within the Lake Okeechobee agricultural area under the Central and Southern Florida Flood Control Project. As shown on plate 1, Hillsboro Canal is one of the major canals serving that extensive area. The area lies immediately south of Lake Okeechobee in central Florida, and is composed of organic soils formed by the decay of sawgrass and other water-loving plants. Originally, the area was practically flat, with a slope to the south of about 1 foot in 10 miles. The present ground surface has been modified by the drainage afforded by the existing canals which have accelerated the subsidence of the organic soils through oxidation, and ground elevations along the canals have been lowered practically uniformly as shown by examination of the contours on plate 1. Ground elevations of areas away from the canal have not been affected since the canal was not effective in lowering water elevations over a wide area. The excavation of Hillsboro Canal was started in 1913 by the Everglades Drainage District to drain the area and make it suitable for agricultural production. Since work on the canal was dependent on available funds, it was not completed until 1929. The canal serves an area of about 218 square miles (see plate 2). The bottom width varies between a maximum of 70 feet and a minimum of 18 feet, with an average of about 44 feet. In the reach under consideration (about 24 miles long) the average bottom of the canal is about elevation 5 feet above mean sea level, or about 9 feet below the average ground elevation. There are continuous spoil banks on both sides of the canal, which, in reaches near Lake Okeechobee, have been regraded to serve as roadways. The purpose of the canal was to remove excess floodwaters from the area and discharge them north to Lake Okeechobee and southeast to the Atlantic Ocean near Fort Lauderdale. However, drainage afforded by the canal was limited to the north by Lake Okeechobee stages and to the Atlantic Ocean by the narrow, shallow canal provided southeast of the area under consideration. Locks were provided near each end to prevent overdrainage during dry periods and to provide access to the area by boat.



LAKE OKEECHOBEE AGRICULTURAL AREA PLATE 1

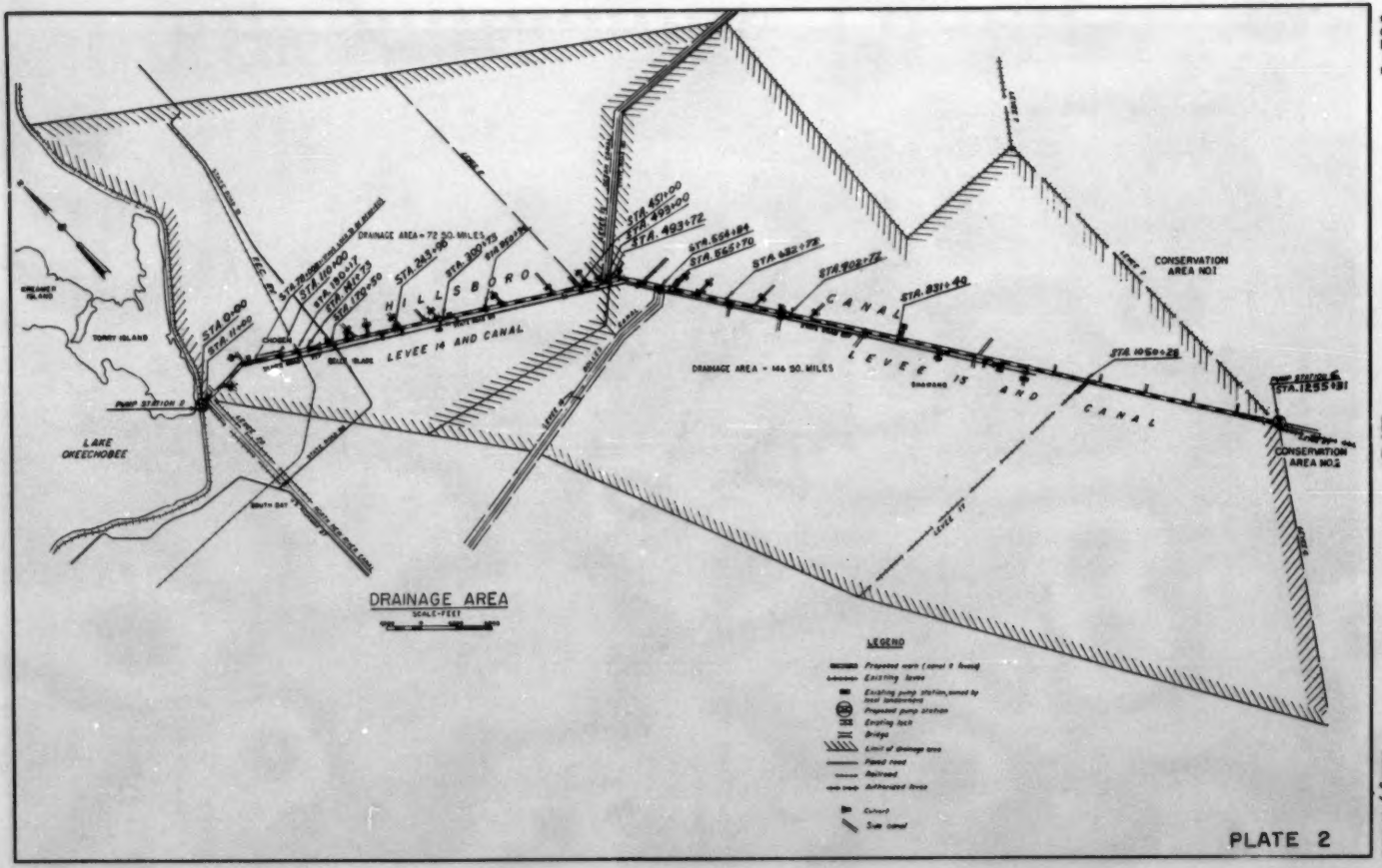

DRAINAGE AREA = 72 SQ. MILES
DRAINAGE AREA = 146 SQ. MILES
HILLSBORO CANAL
LEVEE 14 AND CANAL
LEVEE 13 AND CANAL
CONSERVATION AREA NO.1
CONSERVATION AREA NO.2
LAKE OKEECHOBEE
TORRY ISLAND
PUMP STATION 2
STA. 0+00
STA. 11+00
STA. 110+00
STA. 245+00
STA. 451+00
STA. 493+00
STA. 831+44
STA. 1050+28
STA. 1255+81
DRAINAGE AREA
SCALE - FEET
LEGEND
Existing levee
Existing pump station, owned by local sponsors
Proposed pump station
Existing lock
Bridge
Paved road
Railroad
Culvert
State canal

PLATE 2

Improvement under Central and Southern Florida Flood Control Project

In spite of the canal, the area was subjected to severe flooding at frequent intervals. After the 1947 flood, which inundated most of the area for 4 to 5 months, it became apparent that development of a drainage system adequate for the entire area was beyond the financial ability of the individual landowners. In 1948 the Congress, acting on the appeal of local interests, authorized enlargement of the canal as a part of the Central and Southern Florida Flood Control Project. The project is a joint undertaking of the Federal Government (with the Corps of Engineers as the constructing agency) and the State (with the Central and Southern Florida Flood Control District as representatives of local interests). Since early experience had indicated that there was insufficient natural slope to provide for gravity removal of floodwaters, the construction of two pumping stations on the canal (one at either end of the Lake Okeechobee agricultural area) was authorized as a part of the project. The portion of the area lying north of Ocean Canal (about 72 square miles) will be drained to Lake Okeechobee by pumping station 2 located near the lake, while discharge from the remaining 146 square miles will be discharged through pumping station 6 into the conservation areas on the south—provided under the project.

Under the project, the canal will provide water control to its drainage area, remove excess floodwaters, supply additional water from Lake Okeechobee during drought periods, and maintain ground-water elevations for agricultural use, which will minimize subsidence of the organic soils. After evaluation of all factors—soil characteristics; land use, type, and diversity; and canal storage—the flood-removal capacity of the system was fixed at three-fourths inch a day. Experience in the area indicated that for desirable conditions during nonflood periods water should be supplied at a maximum rate of about 4.3 c.f.s. a square mile with water levels in the main canal maintained about 1.0 to 1.5 feet below the average ground elevation. Plate 3 shows the canal capacity required at points along the canal to meet the design criteria.

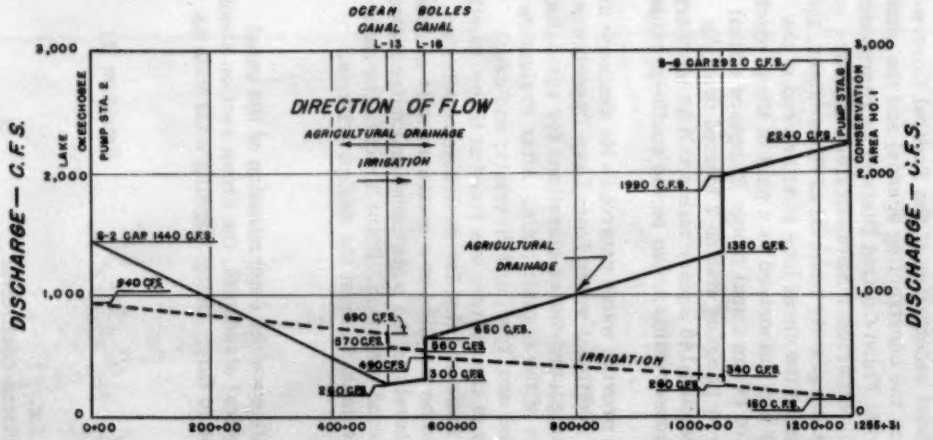
Design of Canal Cross Section

There are many factors which influence the determination of the canal cross section. First, from a theoretical standpoint, the cross section should provide the least possible resistance to flow. Using Manning's formula as the basis of discharge computation:

$$Q = \frac{1.486}{n} AR^{2/3} S^{1/2} \qquad \text{Equation (1)}$$

where Q = discharge in c.f.s.
n = hydraulic roughness coefficient
A = cross-sectional area in square feet
R = ratio of the canal cross-sectional area to the wetted perimeter
and S = water-surface slope in feet per foot

At any point along the canal, all factors with the exception of R (hydraulic radius) may be considered as constants. Hence, it can be seen that the discharge will vary directly with the hydraulic radius R. It can be readily demonstrated that the deeper the canal the greater the discharge per unit



DESIGN FLOW AND DISTRIBUTION

NOTES :

1. DESIGN DISCHARGE FOR AGRICULTURAL DRAINAGE IS EQUAL TO $\frac{1}{4}$ INCH PER DAY (20.0 C.F.S. PER SQUARE MILE) FROM DRAINAGE AREA.
2. DESIGN DISCHARGE FOR IRRIGATION WILL PROVIDE 4.3 C.F.S. PER SQUARE MILE ON THE DRAINAGE AREA.

PLATE 3

area as long as the canal width exceeds that necessary to prevent excessive eddy loss due to side interference. For trapezoidal cross sections, the relation of canal depth to canal width, giving the minimum wetted perimeter or maximum hydraulic efficiency, has been expressed by the equation:

$$b = 2D\left(\sqrt{1+Z^2} - Z\right) \qquad \text{Equation (2)}$$

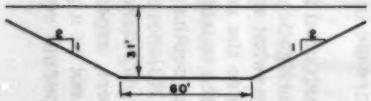
where: b = bottom width in feet
D = depth of water in feet
Z = ratio (horizontal to vertical) of side slopes

However, there are practical factors which tend to limit the canal depths which can be provided economically. One of the most important is the equipment which will be used in the excavation. The use of hydraulic dredging equipment is most favorable to excavation of a wide, shallow channel. The economical depth will vary with the size of dredge employed. Where excavation is by dragline or monitor, depths up to 40 or 45 feet can be excavated without increase in unit cost of handling the materials, provided the top width of the canal does not exceed 350 feet. If dragline operation is restricted to one bank, bottom width of the canal should not exceed about 50 feet. When material to be excavated must be blasted, the cost of drilling will also materially affect the cost of excavation and may be the governing influence on the most economical cross section and depth.

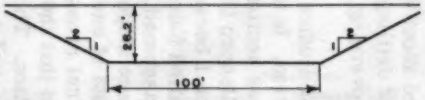
In the design of Hillsboro Canal, preliminary cost studies were made to determine design of the most economical cross section. In those studies, the canal side slopes were fixed to consideration of cross section with side slope of 1 vertical on 2 horizontal. Design studies for Hillsboro Canal, which will be discussed later, were based on side slopes of 1 on 1 because of the consolidated character of the material which more detailed foundation exploration developed. Three typical cross sections were assumed in the cost study, each having the same conveyance with a water-surface slope of 0.00005. The variation of volume of excavation with depth, unit cost of excavation with depth, and cost of excavation with depth, together with typical cross sections used in the study, are shown on plate 4. The study indicated that the most economical depth was about 33 feet below average ground elevation. The sharp increase in cost of excavation at greater depths (due to the cost of drilling and blasting) was sufficient to counterbalance at that depth the increase in hydraulic efficiency of a deeper canal.

There are also other factors which should be considered in the design of the canal cross section—for example, the needs of navigation or maintenance of the canal. Maintenance of the canal will vary somewhat with depth, since the growth of organic plants is limited to depths where the sunlight necessary for growth is available. The waters draining from the mucklands of the Everglades tend to be highly colored with tannic acid, and depths penetrated by sunlight are limited to about 12 feet. Hence, in the Hillsboro Canal area the growth of aquatic vegetation is limited from a practical standpoint to water depths of 12 feet or less. In water deeper than 12 feet, experience indicates that growth of aquatic vegetation on the bottom will not be a problem. In other regions, characteristics of water and climate may permit vegetative growth at greater depths.

WIDTH-DEPTH ECONOMICS



DESIGN A



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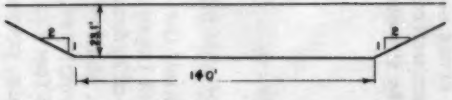
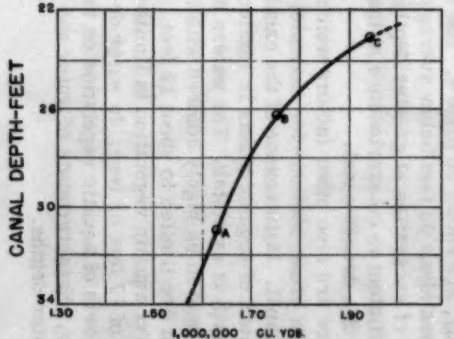
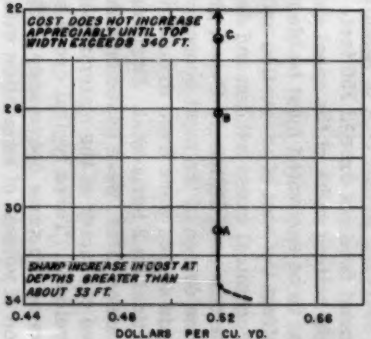


DESIGN C

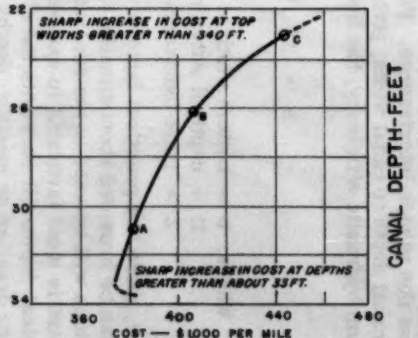
TYPICAL CANAL CROSS-SECTIONS



VOLUME OF EXCAVATION



UNIT COST OF EXCAVATION



COST PER MILE OF CANAL

PLATE 4

962-B IR 2 May, 1956

Design of the Water-Surface Profile—Gravity Canal

In the reach of Hillsboro Canal from Ocean Canal to pumping station 6 the canal capacity required for removal of floodwaters under design conditions varies from 260 c.f.s. at Ocean Canal to 2,920 c.f.s. at the pumping station—as shown on plate 3. The most economical water-surface profile is the profile which will provide the required capacity with minimum excavation. Since in accordance with Manning's formula (equation 1) the cross-sectional area and excavation required will vary directly with the discharge and inversely with the square root of the water-surface slope, the slope of the water surface will vary along the canal for the most economical design. However, if the water-surface slope along the canal is adjusted so that the volume of excavation for a given reduction in the water-surface slope at any point along the canal is a constant, the profile will require the minimum excavation. The design of the canal has been based on this criterion. As an aid in the actual application of this criterion, the diagram shown on plate 5 has been derived. The diagram has been based on the following equation, which, for the most efficient hydraulic trapezoidal canal section with side slopes of 1 vertical on 1 horizontal, gives the variation of the depth-bottom width with cross-sectional area:

$$R = \frac{A}{\frac{A}{D} - D + 2D\sqrt{2}} \qquad \text{Equation (3)}$$

where D = depth of canal in feet
and $\frac{A}{D} - D = b$ = bottom width of the canal in feet

Differentiating equation (3) with respect to D and equating to zero gives:

$$A = 1.8284\, D^2 \qquad \text{Equation (4)}$$

Solving for bottom width and the hydraulic radius:

$$b = 0.8284\, D \qquad \text{Equation (5)}$$

and $$R^{2/3} = 0.5152\, A^{1/3} \qquad \text{Equation (6)}$$

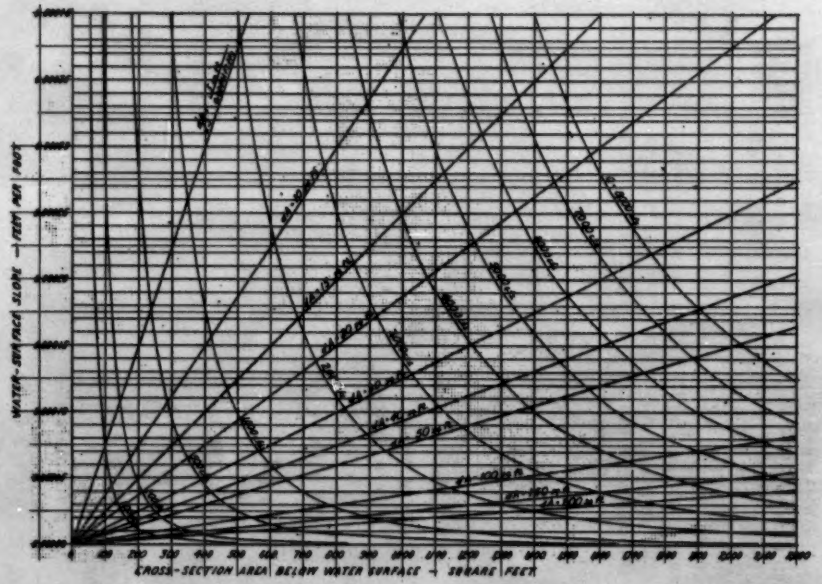
Substituting in Manning's formula (see equation (1)), equation (6) for $R^{2/3}$ and 0.030 for n the hydraulic roughness, Manning's formula becomes:

$$Q = 25.52\, A^{4/3}\, S^{1/2} \qquad \text{Equation (7)}$$

That equation was used to plot the family of discharge curves shown on plate 5. If equation (7) is solved for A:

$$A = \left(\frac{Q}{25.52}\right)^{3/4} S^{-3/8} \qquad \text{Equation (8)}$$

Assuming Q is constant for any one discharge curve and differentiating equation (8):



CANAL DESIGN CURVES

PLATE 5

$$\frac{dA}{dS} = -\frac{3}{8}\left(\frac{Q}{25.52}\right)^{3/4} S^{-11/8} \qquad \text{Equation (9)}$$

Solving equation (7) for Q:

$$\frac{dA}{dS} = -\frac{3}{8}\,\frac{A}{S} \qquad \text{Equation (10)}$$

By this relation it is possible to determine the variation of the cross-sectional area with the water-surface slope for a small change in slope. The $\frac{dA}{dS}$ lines of plate 5 were plotted to indicate a change of 0.00001 foot per foot in the water-surface slope. In the application of the procedure to a design problem, the canal should be divided into a number of reaches of equal length. The reaches should be selected so that the average design discharge within the reach will not deviate materially from the maximum discharge at any point within the reach. A trial solution can be made considering the canal as a single reach and using the discharge weighted for length along the entire canal and the average slope based on the available difference in elevation. From the curves on plate 5 the approximate $\frac{dA}{dS}$ for the entire length of canal under consideration may be determined. Using this approximate $\frac{dA}{dS}$, the water-surface slope and area required for each reach based on the average discharge can be estimated. From the water-surface slopes the design should be checked by determining the difference in water elevation within the length of canal under consideration. If it differs from the available difference in elevation, the $\frac{dA}{dS}$ value should be adjusted and the procedure repeated until a reasonable agreement in slope is obtained. It should be understood that the procedure is most valid if the design water surface is at or near the ground surface along the canal under consideration and the wetted cross-sectional area is practically equal to the area excavated. If variations of the water surface fall materially below the ground surface, the procedure should be adjusted to consider the variation of excavation which will result.

Design of Water-Surface Profile—Pumped Canal

In the design of a canal which will be pumped, the problem is further complicated since the available slope can be adjusted, within reason, by change in pumping station characteristics. In order to arrive at a design which will serve the area drained at the least possible cost, care must be taken to determine the most economical combination of canal and pumping station designs. Since a large portion of the cost of a pumping station is the cost of operation and maintenance, the design should be based on the lowest annual cost over the life of the project rather than the construction cost if a valid comparison is to be made.

In order to develop the overall economics of the Hillsboro Canal drainage system, three criteria for the maximum water surface were considered—(a) Not over 2.0 feet above the average ground elevation; (b) at the average ground elevation; and (c) about 2.0 feet below the average ground elevation.

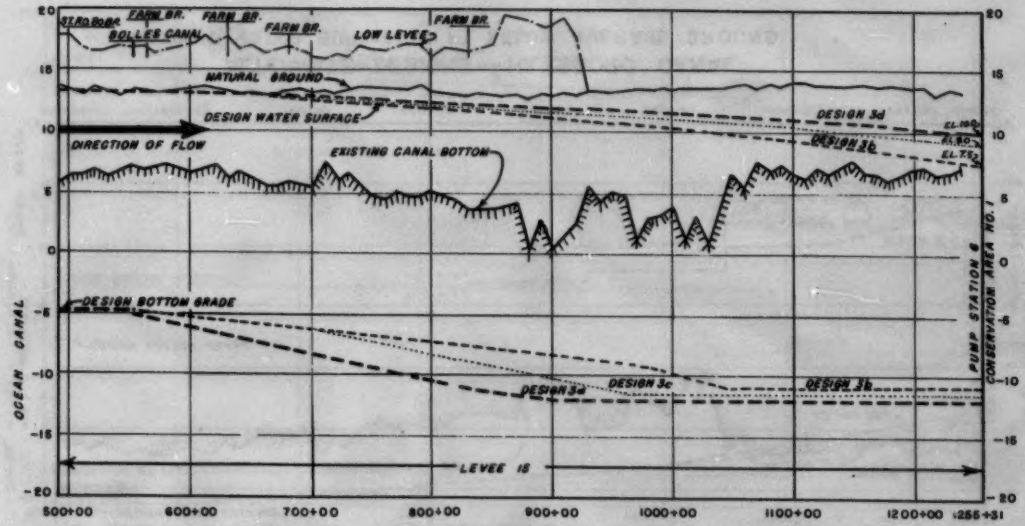
The first criterion would require local landowners to pump all excess rainfall, while the third would permit limited gravity drainage. It would be possible to eliminate pumping of excess rainfall by local pumping station along the canal by providing even lower water-surface profiles. In any event, pumping stations are required by local landowners to raise irrigation water from Hillsboro Canal to an elevation where it will flow by gravity to their lands. The cost of pumping excess floodwaters required by local landowners under each design has been based on the study of existing pumping stations in the area. Since water-surface profiles along the canal during irrigation periods would be at or near optimum elevation for all studies, the annual costs of pumping for irrigation would be constant under all design drainage conditions. Therefore, comparison has been made of costs for removing excess rainfall only.

Designs for Hillsboro Canal from Ocean Canal to pumping station 6 were prepared which would provide for conveyance of the water to the pumping station without exceeding the maximum water-surface criteria. In all studies, design of the canal was controlled by irrigation requirements in the northwest reaches of the canal and by drainage requirements in the southeast reaches near pumping station 6. Also, in all design studies the excavated material exceeded the embankment requirements for levees along the canals. Design studies of the canal are shown on plates 6, 7, and 8. Estimates of initial and annual costs for alternative design studies are presented in table 1 and shown graphically on plates 9 and 10.

The estimated costs of canal enlargement vary inversely with the available slope; the greater the difference in elevation practicable between the ends of the canal under consideration, the smaller the enlargement (and hence cost) required. The costs also materially decrease with an increase in the water-surface profile criteria. However, other design factors may limit the range of water-surface profile which can be considered practical. If the design water surface is raised materially above the natural ground elevation gravity discharge of floodwaters from lands adjacent to the canal is impossible, and remedial measures are required to prevent excessive seepage damage in lands adjacent to the canal. The savings possible through raising the design profile is also limited by the canal enlargement required to meet other design criteria, such as supplying irrigation water. For example, if the water-surface profile is varied a maximum of 2 feet above the average ground, the design of the northerly 10 miles of the canal, as shown on plate 8, is based on the volume of irrigation water required rather than the flood-removal criteria. With lower water-surface criteria, discharge of floodwaters is the governing criterion. Estimates of initial and annual costs for designs considered for pumping station 6 are presented in table 2 and shown graphically on plates 9 and 10. The costs of pumping installation required vary directly with pump-intake elevation. The size of the engine utilized to drive the pump is the predominating influence on those costs.

Comparison of Construction Costs

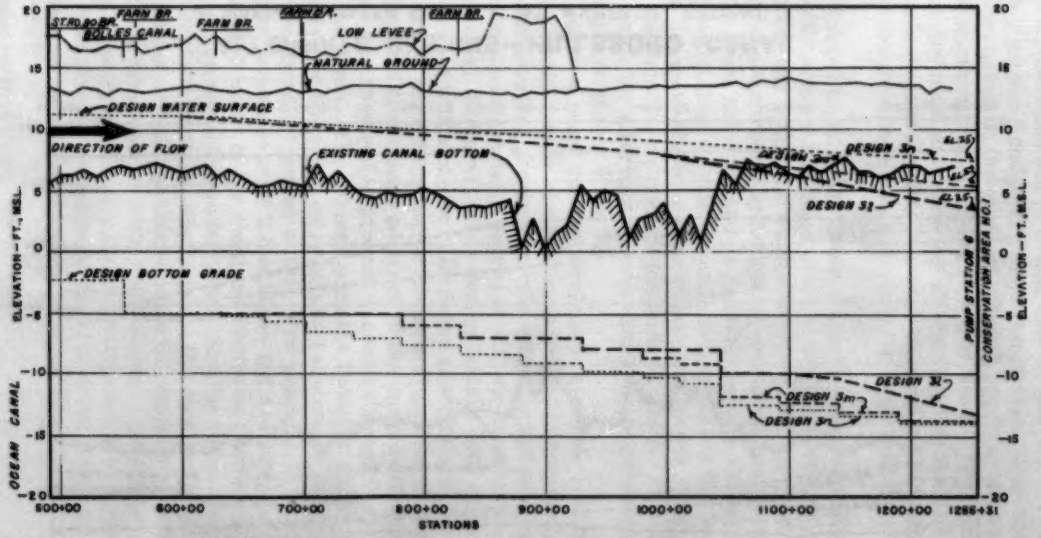
A graphic comparison between the construction costs of alternative pump and canal designs can be made by relating all designs to the pumping station intake elevation as shown on plate 9. Separate curves for canal construction costs have been presented for each of the three maximum water-surface profiles considered. Since pumping station construction costs do not vary with



ALTERNATE DESIGNS—HILLSBORO CANAL

MAXIMUM WATER SURFACE AT AVERAGE GROUND

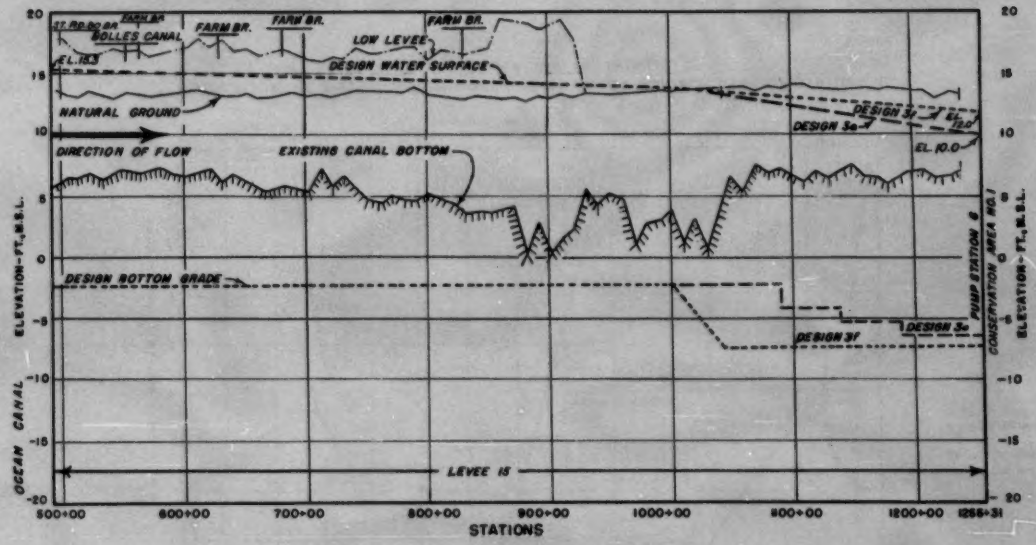
PLATE 6



ALTERNATE DESIGNS — HILLSBORO CANAL

MAXIMUM WATER SURFACE 2 FT. BELOW AVERAGE GROUND

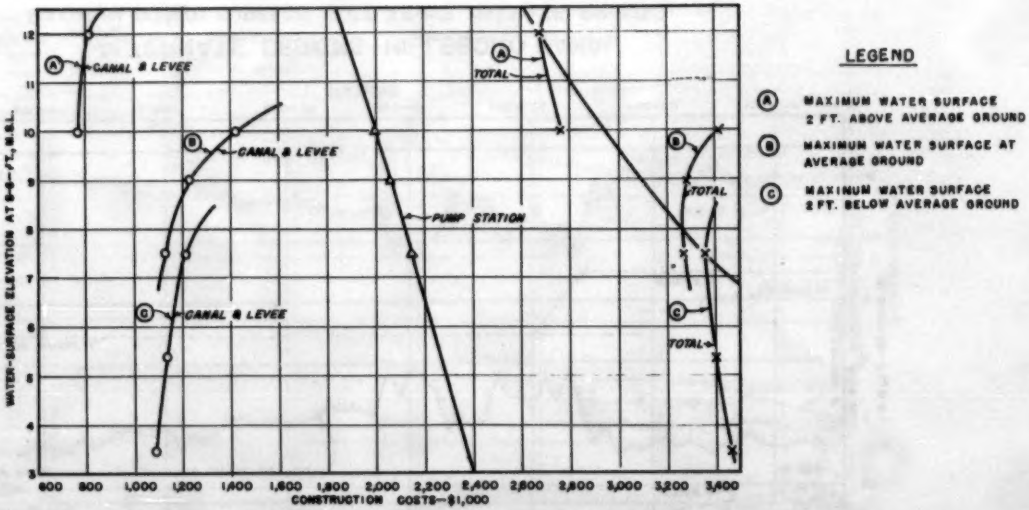
PLATE 7



ALTERNATE DESIGNS-HILLSBORO CANAL

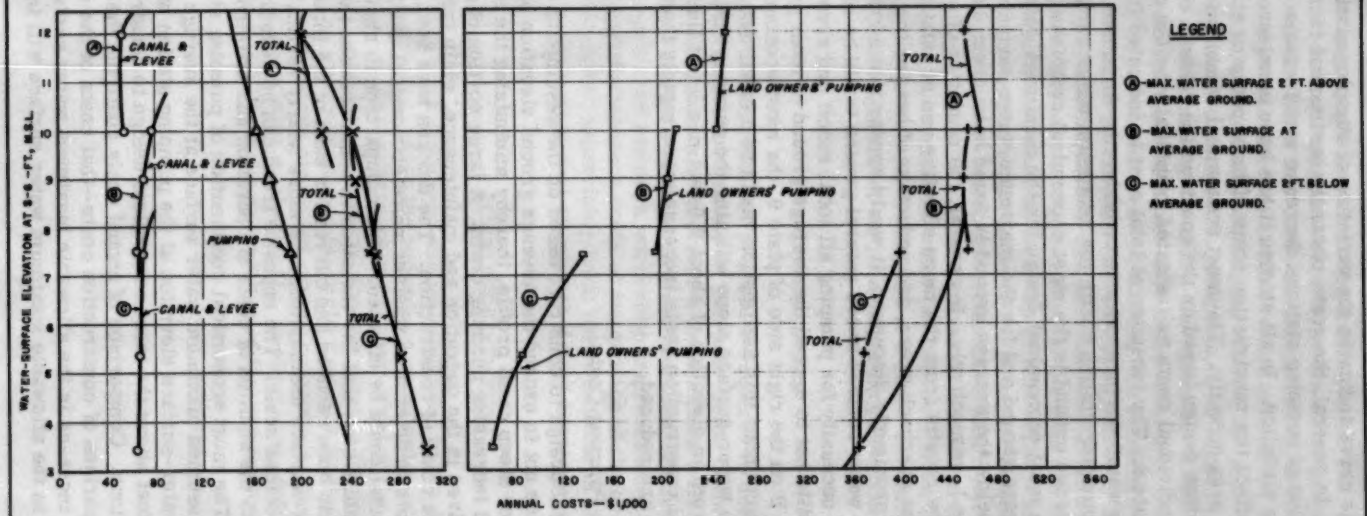
MAXIMUM WATER SURFACE 2 FT. ABOVE AVERAGE GROUND

PLATE 8


WATER-SURFACE ELEVATION AT S-6—FT., M.S.L.
CONSTRUCTION COSTS—$1,000
600 800 1,000 1,200 1,400 1,600 1,800 2,000 2,200 2,400 2,600 2,800 3,000 3,200 3,400
CANAL & LEVEE
CANAL & LEVEE
CANAL & LEVEE
PUMP STATION
TOTAL
TOTAL
TOTAL
LEGEND
MAXIMUM WATER SURFACE 2 FT. ABOVE AVERAGE GROUND
MAXIMUM WATER SURFACE AT AVERAGE GROUND
MAXIMUM WATER SURFACE 2 FT. BELOW AVERAGE GROUND

COMPARISON OF CONSTRUCTION COSTS WITH WATER SURFACE AT PUMP STATION 6

(COSTS INCLUDE CONTRACT COST, SUPERVISION, AND OVERHEAD)



COMPARISON OF ANNUAL COSTS WITH WITH WATER SURFACE AT PUMP STATION 6

(COSTS INCLUDE AMORTIZATION AND INTEREST ON FOLLOWING ITEMS: CONTRACT COST, ENGINEERING, SUPERVISION, OVERHEAD, RIGHTS-OF-WAY AND RELOCATIONS, AND BRIDGE COST; PLUS ANNUAL MAINTENANCE AND OPERATING COST)

PLATE 10

canal criteria, a single curve indicates the variation of pumping station costs with intake elevation. In general, the costs of canal construction increase and the costs of construction of pumping stations decrease with increase in the pumping station intake elevation. In all studies it has been considered that the design would not affect the construction costs of local pumping stations required to serve the area directly. The most economical combination of canal and pumping station design based on the construction costs is obtained by summation of the individual costs as indicated graphically by the curves on the right side of plate 9. The variation of total cost is indicated for each of the three maximum water-surface criteria considered. An intake elevation of 12.0 feet m.s.l. at pumping station 6 with the maximum water surface not over 2.0 above the average ground is the most economical combination to construct. Similarly, the most economical design for the maximum water surface not to exceed the average ground and for the maximum water surface not to be less than 2.0 feet below the average ground is found to be about 8.0 feet m.s.l. and 7.5 feet m.s.l. respectively. In general, the reduction of costs with the higher profiles results from the more effective use of existing canal cross section and canal overbank areas, and reduction of head at the pump station. However, as previously discussed, it would appear that adoption of a design with maximum water surface above natural ground would be impracticable because of the necessity for pumping all local runoff and seepage, and a maximum water profile not to exceed the average ground is most practical. As indicated by curve B on the right side of plate 9, the most economical combination to construct under this assumption would be a canal designed with a relatively steep water-surface slope utilizing the pumping station to discharge the water from an elevation of about 8.0 feet m.s.l. At flatter canal slopes, the canal construction costs increase more rapidly than the pumping station costs are reduced.

Comparison of Annual Pumping Costs

The most economical design to construct based on the assumption of the maximum water surface not to exceed the average ground elevation has been found to utilize a rather steep canal profile, thereby minimizing the costs of canal construction and increasing pumping costs. A large portion of pumping station costs are involved in the operation and maintenance, while canal costs are concentrated in the costs of construction. The designs have been compared on an annual basis to determine whether more economical designs of pumping station and canal could be effected. This comparison is shown on plate 10. It can be readily seen that the variation in costs between the alternative canal designs has been reduced and curves for each of the three alternative maximum water-surface assumptions are more nearly vertical, even with a much larger abscissa scale. The opposite trend can be seen in the costs of pumping due to the addition of costs of operation and maintenance of the pumping station. The most economical combination of pumping station and canal design for assumed maximum water surface at the average ground is found to be with a water-surface elevation at the pumping station of about 10 feet m.s.l., or 2.0 feet above the most economical design to construct under the same assumptions. Comparison of annual costs confirms the conclusions reached by comparison of construction costs—that costs of the drainage system decrease with increase in the allowable maximum water surface. However, an increase in the allowable maximum water surface will increase

the costs of pumping water into the canal. The curves on the right side of plate 10 have been prepared to determine the effect of local pumping on the design selected. When that cost—considered on an annual basis for the design assuming water surface at the average ground—is added to the annual costs of the project canal and pumping station, the pumping station intake elevation is found to be about 9.0 feet m.s.l., or about 1.0 foot below the optimum if local pumping costs are disregarded. It can also be seen that overall costs increase with increase in the allowable maximum water surface. The reduction is accomplished by shifting the pumping from the local pumping station to the more economical large pumping station. However, the lowering of the design water surface in this area materially below the average ground surface would increase soil subsidence of the peat and muck soils. Maintenance of the water surface as near the ground surface as possible is essential for most effective exploitation of the area, and hence canal and pumping station design has been based on an allowable water-surface profile as near the average ground surface as practicable. In other areas where soils will permit greater differences in water levels, the studies indicated that material economy may result from adoption of a lower allowable water-surface profile and concentration of all pumping at large central pumping stations.

CONCLUSIONS

The paper summarizes the procedure required to design an economical drainage system, either gravity or pumped. Some of the factors which from a practical standpoint may exercise a predominant influence in the design are presented. It can be readily seen from economic studies that detailed economic analysis may result in worthwhile improvements in design. Where operation and maintenance costs of any portion of the system—such as pumping stations—differ appreciably from the remainder of the system, costs must be analyzed from an annual standpoint if true economy is to be realized.

ACKNOWLEDGMENTS

The design work discussed was accomplished in the Jacksonville District, Corps of Engineers, under the immediate supervision of Messrs. L. L. Burnet and J. E. Harns, present and former chief of the Engineering Division, respectively, and Mr. H. A. Scott, former chief of the Planning and Reports Branch. The writer wishes to thank the Corps of Engineers for permission to use the information presented, and to acknowledge the assistance of his engineering associates, including Mr. N. Higginson, A.M., ASCE and Mr. J. H. Martin, J. ASCE, in the preparation of the manuscript.

TABLE 1

Hillsboro Canal cost estimates

Item	Maximum water surface 2ft. above average ground (elev. 15.3 ft., m.s.l.)		Maximum water surface at average ground (elev. 13.3 ft., m.s.l.)			Maximum water surface 2 ft. below average ground (elev. 11.3 ft., m.s.l.)		
Design designation	3e	3f	3b	3c	3d	3l	3m	3n
Criteria								
Water-surface elevation at S-6 (ft., m.s.l.)	10.0	12.0	7.5	9.0	10.0	3.5	5.4	7.5
Limiting velocity (ft./sec.)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Available fall (ft.)	5.3	3.3	6.0	4.5	3.5	8.0	6.1	4.0
Bottom width (ft.)	20	20	12 to 15	12 to 15	12 to 15	20	20	20
Quantities								
Excavation, soft material (cu.yd.)	335,000	361,500	482,420	524,600	606,700	496,300	531,000	577,700
Drilling and blasting (sq.ft.)	1,746,000	1,820,000	2,846,000	3,146,000	3,746,000	2,558,200	2,636,700	2,781,700
Excavation, rock (cu.yd.)	502,500	542,300	723,700	787,000	910,000	744,400	796,600	866,600
Culverts (Job)	1	1	1	1	1	1	1	1
Construction costs								
Excavation, soft material	$67,000	$72,300	$96,484	$104,900	$121,340	$99,260	$106,200	$115,540
Drilling and blasting	261,900	273,000	426,900	471,900	561,900	383,730	395,500	417,260
Excavation, rock	201,000	216,900	289,480	314,800	364,000	297,760	318,640	346,600
Culverts	80,700	80,700	80,700	80,700	80,700	80,700	80,700	80,700
Contingencies, including supervision, inspection, and overhead	158,300	166,600	231,606	252,000	292,400	223,350	233,560	248,900
Total construction costs	768,900	809,500	1,125,200	1,224,300	1,420,300	1,084,800	1,134,600	1,209,000
Annual costs								
Interest at 2.5 pct.	23,900	24,900	33,200	35,900	41,000	32,200	33,500	35,400
Amortization of construction costs at 2.5 pct. for 50 years	8,300	8,700	12,100	13,200	15,300	11,700	12,200	13,100
Amortization of State Road 80 bridge at 2.5 pct. for 40 years	100	100	100	100	100	100	100	100
Amortization of R/W and relocations at 2.5 pct. for 50 years	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400
Annual maintenance (14.2 miles of canal) and bridges	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Total annual costs	53,700	55,100	66,800	70,600	77,800	65,400	67,200	70,000

NOTE: All designs provide for levees on either berm, with minimum crest elevation 4 feet above the water surface.

TABLE 2

Cost estimates--pumping station 6

Design designation	Alternate designs		
Criteria			
Intake elevation (ft., m.s.l.)-----	7.5	9.00	10.0
Average head (ft.)-----------	9.9	8.4	7.4
Construction costs			
Structure-----------	$650,000	$640,000	$630,000
Operating equipment-----------	1,052,000	992,000	952,000
Contingencies, including supervision, inspection, and overhead--	441,200	423,100	410,100
Total construction costs----------	2,143,200	2,055,100	1,992,100
Annual			
Interest at 2.5 pct.----------	56,200	54,000	52,300
Amortization of structure costs at 2.5 pct. for 50 yrs.----------	8,900	8,600	8,600
Amortization of operating equipment costs at 2.5 pct. for 25 yrs.-----	40,700	38,400	36,800
Annual maintenance and operation---	87,000	75,000	68,000
Total annual costs----------	192,800	176,000	165,700

JOURNAL
IRRIGATION AND DRAINAGE DIVISION
Proceedings of the American Society of Civil Engineers

ECONOMIC CRITERIA FOR WATER DEVELOPMENT PROJECTS

Jewell J. Rasmussen*

Importance of Water Resource Development

It is significant to note at the outset that we have had two major studies, both national in scope, of water resource problems within the last five years. In 1950 the President's Water Resources Policy Commission made an elaborate study with recommendations for a comprehensive policy of water resources development.[1] In 1952 industrial water supply received special emphasis by the President's Materials Policy Commission.[2] In addition to these major studies, water resources receive considerable attention in The Twentieth Century Fund's monumental volume, America's Needs and Resources, A New Survey.[3]

Being an economist, I am sure you expect me to say something about the supply and demand situation relative to the nation's water resources. As a prelude to my topic, let me briefly review with you some of the findings of recent studies pertaining to supply and demand.

Water is perhaps our most widely used resource. As seen in Table 1, the daily withdrawal of water for all uses in 1950 was estimated at 185 billion gallons, of which 170 billion gallons were fresh water and 15 billion gallons were salt water. These estimates are on a gross basis and include a large but unknown amount of reuse of water. Of the total consumption, 48 per cent was used in irrigation, 43 per cent was used directly by industry, and 9 per cent was used by industry, households, and others through municipal or rural water systems.

Note: Discussion open until October 1, 1956. Paper 977 is part of the copyrighted Journal of the Irrigation and Drainage Division of the American Society of Civil Engineers, Vol. 82, No. IR 2, May, 1956.

* Prof. of Economics, Univ. of Utah, Salt Lake City, Utah.

1. The general report of the Commission is contained in Volume 1, A Water Policy for the American People. Volume 2 contains the details of ten river basin studies, and Volume 3 is devoted to water resources law.
2. Resources for Freedom: Vol. I, Chapter 10, "Supplying Industry with Water," and Vol. V, Report 9, "Water for United States Industry."
3. 1955; Chapter 17, "Land and Water Conservation and Developments," and Chapter 21, "Natural Resources."

TABLE 1

ESTIMATED TOTAL WITHDRAWALS AND REQUIREMENTS FOR WATER 1950 AND 1975

	Estimated withdrawals 1950		Estimated requirements 1975		Increase 1950-1975	
	Billion gallons per day	Per cent of total	Billion gallons per day	Per cent of total	Billion gallons per day	Per cent increase
Municipal and rural*	17	9	25	7	8	50
Direct industrial	80**	43	215	62	135	170
Irrigation	88	48	110	31	22	25
Total	185	100	350	100	165	90

* Roughly half of total municipal supplies are used industrially.
** Includes an estimated 15 billion gallons per day of salt water used in industry for cooling.

Source: The President's Materials Policy Commission, Resources for Freedom, Vol. I (June 1952), p. 51.

Since 1900 the total water withdrawal in the United States has doubled on the average about every 25 years. There are good reasons for believing that between 1950 and 1975 total water requirements will again nearly double. The rising plane of living includes greater use of such appliances as air conditioning units, automatic washing machines, and dishwashers which increase the per capita domestic use of water.

Of greater importance is the rapidly growing demand for industrial water supplies. Advances in technology are adding greatly to our industrial water requirements, both in the quantity and quality of water needed. This situation is especially true in the manufacturing of synthetic materials such as rayon, nylon, synthetic rubber, and numerous chemicals.

The estimates for 1975 as given in Table 1 reflect both the increase in total requirements and the change in relative use of water. Total daily requirements are estimated to increase from 185 to 350 billion gallons between 1950 and 1975, an increase of 90 per cent. Estimated percentage increases in daily requirements for the three major use categories in 1975 over 1950 are as follows: municipal, 50 per cent; direct industrial, 170 per cent; and irrigation, 25 per cent. It will be noted that in 1950 direct industrial use accounted for 43 per cent of total withdrawals, while in 1975 this use is estimated to be about 62 per cent of the total. About four-fifths of the increase will be for the estimated rise in industrial water requirements.

Because of the great disparity in the availability and use of water in the various states, the practical problems of supplying the required quantity and quality of water are regional rather than national. As reported by the President's Materials Policy Commission,

> Most areas in the arid West and some in the humid East, especially in the manufacturing belt, are reaching the limit of pure water supplies. Probably none of the ten largest water-using states (California, New York, Idaho, Illinois, Ohio, Colorado, Pennsylvania, Texas, Michigan, and Montana), with the possible exception of Texas, could double the withdrawal of good quality water without heavy cost. A few states already are hard-pressed. . . .
>
> On the other hand, probably half the states could at least double present withdrawals at relatively low cost, and a few states could increase them 10 or 20 times.[4]

Two serious aspects of the water supply problem have already emerged: A shortage threatens in the face of growing industrial and agricultural needs in the area from the Great Plains to the Pacific Coast, except in the Pacific Northwest, and pollution is becoming a menace in the manufacturing belt from Chicago and St. Louis eastward to the Atlantic Coast.

The availability of water has been an important factor in the geographic distribution of agriculture and industry, and for the long-range future, the limitations on development in certain areas may become quite severe in terms of water supply. As water use approaches the maximum available for withdrawal in more and more areas, water supply will play an increasingly larger role in industrial location and rates of population growth. Indeed, by 1975 water supply may be the most important single factor affecting industrial location.

A possible result of the supply-demand situation in the western states is a reallocation of water use. The rate of population growth in both the Mountain and the Pacific States is greater than for the nation as a whole. Industrialization in this region is proceeding at a rapid rate. Yet in this region, about 90 per cent of the water is used for irrigation. Without development of additional water supplies–and it is now high-cost development–the growing water needs of the western cities and industries, together with the depletion of existing supplies, may eventually force a reduction of irrigated acreage in some areas. Such action, of course, will be strongly resisted.

With respect to the over-all picture, the President's Water Resources Policy Commission concluded that at the midway point in the twentieth century, two facts have become compellingly clear. The first fact is that water is limited in relation to the many and varied needs for its use, and that these needs will grow in size and complexity as the population grows and as industry develops. For this reason, the Commission felt that we can no longer be wasteful and careless in our attitude towards our water resources. Not just in the West, but in every part of the country, we should manage and conserve water if we are to make the best use of it for future development.

The second fact which the Commission believes to be fundamental is that the management, conservation, and use of our water resources is inextricably bound up with the management, conservation, and use of our land and that both are essential to our expansion as a nation. Failure to manage and conserve water causes losses in other natural resources, and failure to manage and conserve these other resources results in the loss of usefulness of our water.[5]

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4. Resources for Freedom, Vol. I, p. 52.
5. A Water Policy for the American People, p. 2.

So much then for the supply and demand aspects and the relative importance of water resources and their development in the United States.

Complex Nature of Evaluation

The development of water and related land resources is a highly complex matter. To do the job right requires a thorough understanding of many aspects of potential projects, including the following: characteristics and interrelationships of relevant resources, modern engineering, industrial and agricultural technology, economic trends and impacts, social and cultural forces, and even political relationships. Such completeness of understanding is necessary because development projects must fit effectively into a very complicated physical environment and into an even more complicated social and political environment.

It seems evident, then, that the selection of water development projects must logically be based upon an evaluation which attempts to view the total picture, no matter how complex it may be and no matter how many gaps in information there may be. In other words, criteria for determining the economic justification of water development projects must include consideration of all the various facets of a project.

Among the different aspects are some that are very difficult to evaluate because they are not directly measurable in monetary terms. Included in this category of "intangible" factors are such benefits as national defense, protection of the public health and safety, provision of recreational facilities, preservation of scenic values, and preservation of the national resource base. Failure to give proper consideration to these aspects may result in their complete exclusion or being given undue emphasis by ambitious agencies.

Two additional facts add to the complexity of the evaluation process: (1) the absence of a comprehensive policy for the conservation and development of water and related land resources, and (2) the enormity of the scope and cost of many current projects. Due to the first situation, comprehensive cost estimates have not been developed. However, some studies and estimates have been made by both private and public sources, and from these it would appear that an adequate conservation and development program for renewable resources over the next generation might cost the nation in the neighborhood of 75 to 100 billion dollars in 1950 prices.

In view of the high cost of current and future water development projects, it is imperative that such projects be planned and their feasibility evaluated in terms of important national objectives. Unless this is done, particular projects are difficult to appraise and conflicts among purposes and uses of water become inevitable.

To indicate the nature and scope of future projects, the following estimated costs by the Twentieth Century Fund's new survey are informative:

TABLE 2

ESTIMATED COSTS FOR WATER, LAND, AND FOREST CONSERVATION AND DEVELOPMENT PROGRAMS

Type of Program	Total Cost	Years required
River valley development		
Waterways and port development	$ 7,500	50-75
Flood control	15,000	50-75
Irrigation	10,000	50-75
Hydroelectric power	30,000	50-75
Domestic and industrial water supply	6,250	25
Pollution abatement	10,000	25
Fish and wildlife conservation and recreation	1,250	50-75
Sub-total, River valley development	$ 80,000	
Land conservation and rehabilitation needs	10,500	20
Land development possibilities	9,500	25-50
Forest management for timber production	4,200	25-50
Forest protection and development for nontimber uses	3,600	20-50
Unadjusted total	$ 107,800	
Deduct for duplications between estimates	4,460	
Adjusted total	$ 103,340	

Source: America's Needs and Resources, A New Survey (1955), p. 572.

Securing some sort of agreement upon a set of objectives would itself be no easy task, but certainly there are some aspects of water resource development that most people would approve. The objectives recommended by the President's Water Resources Policy Commission set forth the general frame of reference which this commission would use in project evaluation. These objectives are as follows:

1) The safeguarding of our heritage of useful resources against deterioration from careless use or neglect, thus preventing the ultimate decline of our productivity at the very time when we require an expanding base. Included are all phases of soil conservation, flood management, control of ground waters, control of surface water quality, and sound forestry.

2) The improvement of this heritage and its higher utilization in order to provide, through increasing production of land and water resources, a broader base for a steadily expanding national economy, with its contribution to national security. This objective covers management of our water resources to transform them from ineffective or destructive into beneficial agents, watering arid land, supplying municipal and industrial needs, improving channels for water transportation, and generating hydroelectric power.

3) Opportunity for farms, urban homes, commercial establishments, and industries to make full use of electric power, through a marketing policy for Federal power aimed at encouraging maximum use at the lowest possible rates.

4) Coordination of water and land resources undertakings with specific plans to meet needs of national security.

5) The development of balanced regional economies, with particular emphasis on those which are characterized by low economic opportunity, offering maximum opportunity for farming coupled with nonagricultural rural employment.

6) Provision for expanding cultural opportunities, including all phases of recreational development from wilderness areas to wisely designed, artificial multiple-purpose reservoirs.

7) The protection of the public health, particularly through pollution abatement and control, mosquito control, and all necessary provision for an abundance of high-grade municipal water supply.[8]

To repeat a basic point stated previously, economic appraisal of water resource development must necessarily take into consideration all the various facets of a developmental project. Specific criteria which will be briefly reviewed in the remainder of this paper include the optimum use of resources aspect, the financial aspect, the benefit-cost aspect, the public aspect, the regional balance aspect, and the expansionary effects on income and employment.

Optimum Use of Resources

An important factor in the material well-being of the United States is our relative abundance of natural resources. But even so, this nation is not so richly endowed that we can afford to be extravagant and wasteful with our resources. Even now the rapid rate of depletion in some areas is cause for some concern. Technology is constantly coming to our rescue, it is true, by stretching out the life of limited resources, providing ways to utilize low quality raw materials, or providing new substitutes for scarce resources. Nevertheless, we should not take nor create unnecessary risks but should be conservation-minded and strive to obtain the optimum benefits from our natural resources.

In water resource development, the application of this criterion requires multiple-purpose development; i.e., comprehensive planning and development of all aspects of the collection, conservation, and use of water. Each major project, whatever its primary function, should be a truly multi-purpose installation designed to utilize the full potential benefits of the water: flood control, power generation, land reclamation, navigation, municipal and industrial water supply, recreation, or other relevant uses.

Perhaps a good illustration of this aspect of project evaluation is the controversial issue of one high-level Federal dam or three low-level private dams in the Hells Canyon area of the Snake River. It should be possible to look beyond the politics and the claims and counter-claims of the various pressure groups and come up with a reasonably satisfactory answer to the question, "Which plan of development will result in the fullest utilization–including all relevant uses–of the water in this area of the Snake River?" Optimum use of this resource should carry more weight than the claims of either the public power or the private power lobbies.

Optimum use also requires that water development be carried out in the

form of basin programs which deal with entire basins as units and which take into account all relevant purposes in water and land development. A river basin should be planned as a whole instead of having a patchwork of plans by separate agencies for separate purposes. River basins are the natural subdivisions of our water resources, and watersheds are the natural units in these river basins. Water development should be decided on how best to preserve and utilize the resources of watersheds and river basins to meet regional, state, and local needs within the limits established by the interests of the nation as a whole.

It is perhaps unnecessary to remind a group of engineers that optimum use of resources also requires that a project make the best possible use of the natural features. In other words, the project should be sound from the standpoint of its relationship to the natural environment and from the standpoint of its engineering features.

The controversy concerning the dam sites of the upper Colorado River storage project is a good example of this matter of technical soundness. Surely competent engineering estimates are possible of such important items as evaporation loss, storage capacity, sedimentation control, minimum cost sites, strategic control points, etc. from which the soundest development plan from a technical viewpoint can be determined. It is clear, of course, that technical soundness cannot be determined in a vacuum, but must be related to other considerations, including total costs, the nature of the needs and demands for the goods and services to be supplied by the project, and possible competing uses such as the preservation of wilderness areas or sites for geologic relics. If given the objectives of the project and sufficient data on both technical and financial aspects, it should be possible to make a reasonably objective, intelligent appraisal of the national monument and wilderness area issues and then in the light of these decisions determine a development plan for the project that is best from the standpoint of technical soundness.

The Financial Aspect of Projects

The financial criterion is often a source of controversy and confusion with respect to water resource development. Questions may arise as to the completeness and accuracy of the cost data; misunderstanding often arises relative to the cost to the government and how much project users and beneficiaries are to pay; and there is frequently confusion between financial and economic feasibility of projects.

The costs which will be incurred by the government and the direct financial returns which are to be expected are important elements in determining the feasibility of water development projects. It is perhaps sufficient merely to mention that an accurate estimate must be made of all project costs, including the initial investment costs, subsequent replacement costs, and annual costs of operation and maintenance. Estimation of both costs and financial returns, however, involve a number of complications and must of necessity involve certain arbitrary determinations.

On the cost side, perhaps the most common sources of controversy include the question of interest charges, during both construction and operating phases, the allocation of joint costs, and the question of taxes or payments in lieu of taxes. Time will not permit a detailed discussion of these

points, but let me say that whether or not there may be actual outlays for some of these cost items, it would seem desirable to make estimates of reasonable interest and tax charges and that definite standards be employed in such cost estimation. Since the method for allocating joint costs may predetermine in some instances whether the irrigation, power, flood control, or other purpose of a proposed multiple-purpose project would be judged to be feasible or not, it is especially important to have established definite standards for such cost allocations. Without adequate treatment of these items, cost analysis of water development projects is always subject to question or criticism.

The extent of the financial returns would depend upon whether a Federal agency is to operate the project or whether it is to be operated by a non-Federal unit, and especially upon Federal policy in regard to reimbursement and charges for use. This would involve an estimate of the receipts actually anticipated from the sale of electric power, collection of waterway tolls, payments for irrigation, municipal and industrial water supply, and assessments on conservancy districts, as well as payments on the initial Federal capital investment.

At the risk of exceeding my allotted time, I should like to make a short digression on reimbursement policy. Reimbursement–the question of "Who pays?" and "How much?"–is a crucial issue in water resources development. It influences the scale and character of programs, project formulation, authorization by Congress, appropriations, distribution of benefits and burdens, and various other aspects of water development programs. The growing magnitude of these programs makes the question of "Who pays?" particularly important today.

Present reimbursement practices are for the most part oriented toward isolated, single-purpose functions designed to serve local needs and private interests. Such policy is out of harmony with a more enlightened program of water resources development, comprehensive basin-wide, multiple-purpose development, and the relation of social and economic needs to program formulation.

Four categories of beneficiaries can and should be identified: (1) private individuals or associations, (2) local communities, (3) states or regions, and (4) the nation as a whole.

The private individuals or associations of individuals who gain directly from water development projects are the primary users of the facilities or services of the projects. There is widespread agreement that this class of beneficiaries, insofar as they can be identified and the benefits measured, should pay at least part, if not all, of the cost of facilities or services used.

In some situations the local community is the best means of identifying primary beneficiaries and of assuming their reimbursement responsibilities. This is particularly true for such functions as domestic water supply, local flood control and navigation works, pollution abatement, and recreational use of water. Secondary benefits might also be the basis for some local repayment responsibility.

Because of the intangible nature of the primary benefits from such projects as extensive flood control works, comprehensive watershed protection, recreation facilities, and fish and wildlife refuges, a region or a state may be the unit best suited to assume reimbursement obligations. States might also assume some repayment responsibility for indirect economic effects accruing to the people from such projects as irrigation, land drainage,

navigation, watershed protection, and recreation which has more than local significance.

The national interest in water resources development is undeniably great. It includes many benefits which accrue to the nation as a whole and affect both the security and welfare of the whole population. Illustrative of these benefits are the strengthening of national security, the conservation of soil, water, forest, and mineral resources, and the provision of food, fibers, and electric power at reasonable prices. The amount of Federal contribution should vary with the degree of national interest involved.

There is no easy, simple solution to the problem of reimbursement. The goal should be an equitable distribution of repayment obligations among the private, local community, state, regional, and national interests. In seeking to achieve this goal, a variety of arrangements may be necessary, each one the best that is attainable under the circumstances.

To return to the main stream of thought, the relationship between the total costs and total financial returns would indicate the extent to which the project would be financially feasible. Some people hold the view that all water development projects should be self-liquidating; that is, that financial feasibility should be the sole determining factor in project evaluation. There is a basic fallacy, however, ins such reasoning: it applies to public investment the limitations common to private investment. Public investment in natural resources is not made for profit only, but for the general welfare also. Even Adam Smith, writing 175 years ago, recognized this aspect of public investment.

> The third and last duty of the sovereign or commonwealth is that of erecting and maintaining those public institutions and those public works, which, though they may be in the highest degree advantageous to a great society, are, however, of such a nature, that the profit could never repay the expence to any individual or small number of individuals, and which it therefore cannot be expected that any individual or small number of individuals should erect or maintain.[7]

The important point, then, is that financial feasibility is not the same as economic feasibility. While financial costs and returns should be considered most carefully in the analysis, they alone should not determine the desirability of a project. A more tenable position, it would seem, would be for the Federal Government to seek to conserve and develop the nation's natural resources in such a manner as to provide the broadest and strongest possible foundation for all sorts of economic activities and as to provide the greatest possible scope for all sorts of private investment. Such an approach requires the evaluation of water resources projects on a broader basis than direct financial costs and returns alone, although financial feasibility must certainly play an important role in making final judgments as to project feasibility.

The Benefit-Cost Aspect

An important criterion of water development projects is a careful weighing of the anticipated economic effects or benefits against the total estimated costs of a project.

7. Adam Smith, The Wealth of Nations (New York: The Modern Library edition, 1937), p. 681.

The measurement of net benefits would logically involve the measurement of the total returns to whomever they may accrue, less the costs involved in the realization of the returns, and less the total losses suffered or the added costs imposed by the project. Net benefits, so calculated, would consist of a stream of contributions to the local, regional, and national income and wealth, extending into the future.

Ideally–that is, if the necessary analytical and measurement techniques, as well as the necessary data, were available–the "stream" of contributions to income would be measured along what might be thought of as a series of concentric circles. Thus, measurement would start with the net benefits to the direct users of the services and facilities provided by a project. It would next encompass the net benefits derived by the local processing and trading centers. Then the net benefits to the entire region (as, for example, through increased processing, commercial, and service activities) would have to be determined. And finally, the net contribution to the total real national income would be calculated. Of course, any duplications involved would have to be accounted for in each case. The estimated net benefits, presented in the form of an unduplicated total net contribution to national income, could then be compared with the direct costs of the project. The relationship between project benefits and costs, estimated in each case on an average annual basis, can be presented in the form of a benefit-cost ratio for the project.

Two difficulties arise, however, in the process of determining net benefits. The first one is the practical matter that benefits can never be traded to their ultimate incidence; hence, only primary and immediate secondary benefits can be measured reasonably adequately. The more remote secondary and extended benefits are nevertheless real and must be taken into account. The customary and accepted technique for determining the over-all potential economic effects upon the private sector of the economy is the use of a "multiplier." The multiplier, or technically the "leverage," of a new expenditure is the number by which the original expenditure is multiplied in order to obtain the total change in expenditures or income which it brings about.

A second problem encountered in securing the benefit-cost ratio is the treatment of "intangibles." Only those phases of water development projects which are related to the amount of marketable goods and services made available or which affect income receipts and property values lend themselves to analysis in economic benefit and cost terms. In most instances, a multiple-purpose project will have important benefits which normally do not lend themselves to measurement in monetary terms– such as the saving of human life, the provision of recreational facilities, and the protection of the public health.

Although the "intangible" benefits are not measurable in dollars, they may be quite tangible in other terms and may have reference to some of the most basic national objectives. Because of their peripheral position in benefit-cost formulations, the so-called intangible factors often have not received the detailed analysis they deserve, being presented vaguely or even confusingly related to the benefits arising from the productive facilities.

In general, then, public assistance in water development is justified only if the benefits are widely dispersed and give promise of being greater than public and private costs. Account should be taken of the more remote economic benefits and also of the intangible benefits as well as those to which money values can be ascribed more easily.

The Public Aspect

It has already been indicated that there are various types of public objectives and benefits from water development projects which cannot be measured in the usual commercial terms of the market place. Yet these public values may be among the most important in planning development of water resources. Thus, when one of the objectives is the conservation of resources, evaluation cannot be of the monetary benefit-cost variety. Market prices in part reflect scarcity values, but a project that successfully halted resources deterioration and strengthened the resource base might lead to a reduction in the dollar value of the products and services of resources by making possible an increase in their supply. As so well stated by the President's Water Resources Policy Commission: "This basic conflict between private values based on scarcity and public values based on plenty lies at the very heart of the conservation problem. It is to increase national wealth that government invests public capital in the improvement of the resources base."[8] The accounting of conservation projects will then be largely in physical terms rather than in dollar terms.

Reference was made earlier to the intangible benefits of multiple-purpose projects, including among others national defense, protection of the public health and safety, provision of recreational facilities, and preservation of scenic values. Sometimes these benefits are costless by-products of development for other purposes which increase the productive power of the nation -irrigation and domestic water supply, navigation, power-and sometimes they rise to additional costs. When additional costs are incurred, the benefits and costs should be evaluated on a separate basis. These public or intangible benefits deserve separate consideration because they are "end values" themselves rather than means toward the achievement of end values and make direct contributions to the general well-being of the society through making possible a more wholesome and satisfactory way of life.

When additional costs must be incurred for these intangible benefits, the evaluation process is simply that of determining, through the usual budgetary procedures, how much a given budget can include for such purposes as opposed to other public functions or to a lower total budget. When serving on the staff of the President's Water Resources Policy Commission, I was rather pleasantly surprised to discover, whole reading a special report submitted by the American Society of Civil Engineers, that the civil engineers thought that this nation was rich enough to allocate reasonable amounts of funds for the preservation and improvement of recreational and wildlife facilities in water resources development.

The consideration of public or intangible values in project evaluation is a recent issue that has produced considerable controversy. In earlier single-purpose projects, most of the benefits could be assigned directly to individual beneficiaries. As the Federal Government has undertaken large multiple-purpose basin-wide projects, the public or social values have become increasingly more significant-and often more controversial-in project evaluation, cost allocation, and repayment arrangements.

Unfortunately, well accepted techniques and procedures for establishing the broad public and regional values are lacking. But enough is known to support the view that the social values inherent in our water resources are

8. A Water Policy for the American People, p. 61.

real and vital to the well-being of the nation and should not be lost through failure to achieve complete control and utilization of water resources. Hence, it is essential to supplement benefit-cost analysis with proper consideration of the public values in water development projects.

Regional Balance and Development

A criterion of particular significance to this area, as well as being important to the nation as a whole, is the optimum development of each principal region in the United States. Our vast country is composed of a number of rather well-defined regions, each with a different combination of geographic, economic, and social features. The natural resources of each region are in varying stages of and have varying capacities for development.

The national economy is strengthened to the extent that each region achieves optimum development of its resources. This requires both regional specialization and integrated, balanced development of the economic and social potentialities of each region. Lack of adequate growth and opportunities in a given area result in adverse economic and social conditions: limited employment, low per capita income, outward migration of population, etc.

The history of economic growth and development of the United States reveals that several of the nation's regions have remained to a considerable extent as suppliers of raw materials and have failed to achieve a sound balance among the major segments of industry. Some of the obstacles preventing a better balance and a better pattern of development could be overcome by a sound resources development program of which water development would be an important part.

Let me illustrate this point with two examples close to home. The population of most of the West is growing at a percentage rate much greater than that of the East. While industrialization is increasing to serve the growing needs of the West as well as the whole nation, the future expansion may be greatly curtailed unless large quantities of cheap water can be made available for manufacturing and other industrial uses. If expansion is to continue, the water must come either from new supplies or from the curtailment of irrigation use. For better balance the West needs more industrialization.

As a second example, it is quite evident that additional irrigation water is necessary to make better use of the range economy of the West. As western people know so well, both range and cropland are essential to the livestock industry. Effective use of the range is not possible without some supplemental feed and forage from cropland, and much cropland would have little value except in connection with the use of adjacent range land.

As additional water for irrigation is made available, greater integration of range and cropland will be possible with stabilizing effects upon the whole range economy and providing a greater opportunity for a sounder watershed management program. An increase in the production of farm produced forage should assist in the efforts to reduce the overgrazing occurring on some parts of the range. More livestock can be fed or pastured longer in the spring or even can be kept off the range entirely.

Expansionary Effects of Water Resource Development

As a final criterion, I should like to consider briefly the possible

expansionary effects of water resource development. It was noted previously that proper evaluation requires the careful consideration of all the anticipated economic effects of a project, including the primary, immediate secondary, and the more remote secondary and extended effects on income and employment.

For example, considering just the reclamation aspect of the upper Colorado River project, a conservative estimate of the total annual expansionary effects on income after construction is completed would be between two and three times the yearly incremental crop value. The primary and secondary effects of this additional crop value would result in (1) increased local income to (1) farm operators, owners, and laborers and to (2) labor and capital in the local trading area, and (b) increased income beyond the local trading area from (1) the crop and livestock products being shipped out of a project area thus creating income in transportation, processing, milling, manufacturing, wholesaling, retailing, etc. and from (2) the increased purchasing power of project farmers and all others securing income from the project's production.

Parenthetically, let me say that any discussion of reclamation projects raises the issue of the need for additional agricultural products. Time will not permit analysis of this issue, but on the positive side of the issue I might refer you to the conclusions of the President's Water Resources Policy Commission. After consideration of all the relevant factors–population growth, technological improvements, reduced feed requirements for horses and mules, land deterioration, etc.–the Commission concluded that in spite of surpluses in certain agricultural commodities, it will be necessary to push forward on all fronts if we are to meet the nation's food and fiber needs over the next 25 years.

> On the basis of these estimates, it appears that the increased productivity of existing agricultural acreage, if added to the production available from new lands brought in by irrigation, drainage, flood control, and clearing, is likely to meet the nation's expanding requirements over the next 25 years by a rather narrow margin.[9]

The magnified effects on income and employment may vary considerably among multiple-purpose projects. One may benefit only a limited group; another a wide area. One project may have only a slight expansionary effect; another may lay the foundation for important new industries and provide many new outlets for investments and jobs.

The case for water development projects on the sole basis of the magnified income and employment effects rests upon two conditions: the general level of economic activity in the nation, and the relative merits of water resource development in comparison with other types of programs involving public expenditures.

If high level employment prevailed, due, say, to war or very heavy defense spending, there would be little or no gain nationally in income and employment from these projects. Under these conditions, employment of capital and manpower in water development would mean reduced use of these factors elsewhere. There would be, of course, local and regional increases, but these gains would be offset by decreases elsewhere in the economy. There is a fairly strong belief among professional economists that barring war or

9. A Water Policy for the American People, p. 164.

very heavy defense spending in the years ahead, the chief domestic problem in the United States will be the maintenance of a satisfactory level of income and employment. Population growth and increasing productivity require a steadily increasing number of job and investment opportunities. It could well be that the expansionary effects of water resource development will produce a welcome contribution to the national income.

With respect to the second condition, if government expenditures are necessary to maintain a satisfactory level of total demand, water development projects will have to compete with other types of projects. This will involve judgments as to the relative values of different kinds of public expenditures. Any project–even digging holes and filling them up again–will have some expansionary effects when income and employment are at unsatisfactory levels. But we must insist on striving for the maximum benefits from public expenditures. In the event that direct stimulation of economic activity by government is necessary, it is quite likely that natural resources development will rank fairly high on a list of worthy projects.

CONCLUSION

From this brief survey of some of the criteria for determining the economic justification of water development projects, it is evident that there are many facets involved in the evaluation process. It is also evident that there are now confronting us serious aspects of an adequate supply of water of satisfactory quality in several regions of the nation, and not just in the West, either. Conflicts in the use and development of water resources are also appearing. In view of these conditions, it is being more important that water development be guided by national objectives.

While total benefits should give promise of exceeding total costs–both public and private–there is need for more consideration of the broad national and regional benefits in weighing the benefits against the costs. Financial feasibility is not the same as economic feasibility, but it should be emphasized that a more logical and defensible approach to reimbursement is also in order.

Although this nation is comparatively well endowed with natural resources, we cannot afford to be profligate with them. Hence, we should strive for the optimum use of our water resources–multiple-purpose, basin-wide projects, and optimum regional development.

The economic well-being of a people depends considerably upon the nature of the resource base. Hence, the development and conservation of our natural resources–of which water is a key resource–is imperative in the great task of building an expanding national economy of increasing strength. The significant economic objective of water development programs is to strengthen the resource base of this nation.

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BENEFITS OF WATER DEVELOPMENT PROJECTS

Earl R. Fogarty[1]
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Most of the major Acts of Congress on establishment and authorization of water development projects have required some determination and appraisal of the economic values involved so as to demonstrate the possibility of success of these Federal undertakings. The Reclamation Act of 1902,[2] for instance, provided that the Secretary of the Interior should determine whether a proposed irrigation project was "practicable" before entering into contracts for construction. The Act also provided that annual charges against the lands for use of the water should be determined with a view of returning to the reclamation fund, within 10 years, the estimated cost of construction of the project. This repayment requirement established a relatively severe standard; however, subsequent amendatory and supplementary acts provided for longer repayment periods. At the present time, repayment contracts extend over a period not to exceed 40 years, following a development period of not more than 10 years. Water service contracts may be renewed and specific legislation can and has further extended this period for individual projects.

A further modification of the repayment requirement was the provision which permitted use of power revenues where available to assist in the repayment of costs allocated to irrigation which were beyond the ability of the water users to repay. This provision has been a part of Reclamation Law almost since its beginning. The Act of April 16, 1906, specifically provided that the moneys derived from the disposition of power generated at reclamation projects "shall be covered into the reclamation fund and be placed to the credit of the project from which such power is derived."[3] Subsequent acts have strengthened this provision so that at present power and municipal water revenues in excess of the amounts needed to repay their respective investments with interest are used to assist with the repayment of the irrigation allocation.

With the growth and general acceptance of the multiple-purpose project

Note: Discussion open until October 1, 1956. Paper 981 is part of the copyrighted Journal of the Irrigation and Drainage Division of the American Society of Civil Engineers, Vol. 82, No. IR 2, May, 1956.

1. Chief, Economic Resources Branch, Bureau of Reclamation, U. S. Dept. of the Interior, Denver, Colo.
2. Federal Reclamation Laws, Annotated, 1943 Edition.
3. Federal Reclamation Laws, Annotated, 1943 Edition.

concept in recent years, and application of the provisions of the Reclamation Project Act of 1939, which provides for allocation of a portion of the project costs to the nonreimbursable purposes of flood control and navigation, an even further modification of the repayment requirement was brought about. In addition, a similar provision was included in the Fish and Wildlife Act of 1946, which requires allocation of costs incurred for preservation and propagation of fish and wildlife to be nonreimbursable.[4]

In regard to other types of water development projects, the Congress also established requirements for economic evaluations. Prior to 1936, the requirements for flood control and navigation projects consisted of supplying full information on the present and prospective commercial importance of the projects and their probable commercial benefits, and on the benefits that would accrue to the localities affected by the improvements. The Flood Control Act of 1936, however, was more specific and definitely established the basis for analysis of the economic justification of flood control projects by requiring "that the Federal Government should improve or participate in the improvement of navigable waters or their tributaries, including watersheds thereof, for flood control purposes if the benefits to whomsoever they may accrue are in excess of the estimated costs, and if the lives and social security of the people are otherwise adversely affected." This act applied not only to the Corps of Engineers, but also to the Department of Agriculture, which was given responsibility for watershed treatment projects in the interest of flood control. The Watershed Protection and Flood Prevention Act of 1954 clarified and strengthened the responsibility of the Department of Agriculture in water development projects.

Thus from past legislation, Congress has made clear its desire that economic evaluations be made on Federal water development projects before authorization and construction to determine their economic soundness and justification. It has not, however, established a uniform policy or standards for use in making these evaluations. Instead, establishment of standards and procedures within the general Congressional policy has been left to the several Federal agencies assigned the responsibility for carrying out the different kinds of water development projects. Because of this, some inconsistencies in economic analyses of proposed projects have resulted. Considerable progress has been made, however, by the several Federal agencies in the development and use of mutually acceptable standards and techniques for project formulation and justification. To advocate under present legislative conditions the establishment and use of completely uniform evaluation procedures by the several agencies, would seem to be fallacious. Different legislative requirements, different project purposes, and different kinds of projects require different approaches to economic evaluation. To apply fixed standards or procedures could well give results which would be inaccurate and questionable. Considered judgment, therefore, is required in determining the extent to which procedures for project evaluation should be made uniform.

The advent of multiple-purpose projects and basin-wide developments brought together project purposes which heretofore were appraised differently. Flood control was evaluated on the basis of benefits and costs, whereas irrigation was evaluated on the basis of repayment. In the multiple-purpose

4. Cumulative Supplement to the 1943 Edition, Federal Reclamation Laws, Annotated.

project, it became imperative that a common basis be used for adding or not adding particular functions in project formulation and for equitably apportioning the joint costs to each function. Therefore, the Department of the Interior and the Bureau of Reclamation adopted in 1945 the policy of requiring that benefit-cost analyses be made on all proposed Reclamation projects. This requirement was separate and in addition to the one specified by the Congress for repayment by project beneficiaries of costs of irrigation, power, and municipal and industrial water supply. Adoption of the policy was considered by the Department and the Bureau to be in full accord with various acts of the Congress beginning with the Reclamation Act of 1902, which provided for examinations and surveys of projects and the presentation to the Congress of all facts relative to the practicability of each proposed Federal reclamation project.

At the present time, therefore, the principal agencies responsible for water development projects use the benefit-cost analysis to test the economic justification of a proposed Federal development or river basin program. Also, they use it to determine the size and scope of a Federal project or basin program, they use it to compare the economic merits of different projects, they use it to make allocations of cost, and in certain instances they use it to determine the amount of repayment from conservancy districts and other indirect beneficiaries.

This benefit-cost analysis recognizes widespread effects of water development projects, not all of which are incorporated in repayment analyses. In other words, benefits are not limited to project revenues. Some functions are not required by law to be reimbursed, as in the case of flood control, and in other cases assessment of charges against all project beneficiaries may not be practicable. Consideration, therefore, is given to all project effects, beneficial or adverse, to whomsoever they may accrue, locally, regionally and nationally. Such effects are evaluated as completely as possible on comparable bases, so that the analysis approaches full coverage from a public or national viewpoint.

In a benefit-cost analysis, benefits represent in monetary terms the value of the functions performed by a project. They are project effects comprising increases in the production of goods and services and improvement in the general welfare. Tangible benefits, or those which can be expressed in monetary terms, have been classified in two categories, direct or primary, and indirect or secondary. Direct or primary benefits are the values of immediate products or services of a project. Indirect or secondary benefits are values added over and above the value of the immediate products or services of a project, such as those resulting from subsequent processing. These are more difficult to measure than the direct benefits. Intangible benefits are the increases in production of goods and services and the improvements in general welfare that cannot be measured adequately in monetary terms. They are described in qualitative terms and as specifically as possible.

The principal agencies responsible for water development projects measure tangible benefits for use in economic analyses of proposed projects and give separate consideration to intangible benefits. The practices of these agencies are outlined briefly in the following paragraphs.[5]

5. Proposed Practices for Economic Analysis of River Basin Projects, May 1950.

The Bureau of Reclamation of the Department of the Interior identifies four classes of benefits from reclamation. They are as follows:

Direct benefits include, for irrigation, the increased net farm income; for power, the estimated actual cost of equivalent power from the most likely alternative source, or the estimated value of power to users; for municipal and industrial water, the estimated cost of the most economical alternative means of obtaining the needed water, or the estimated value of the additional water to the consumer; for flood control, the reduction of flood damage; for navigation, savings to shippers and estimated recreational value of harbors and waterways; for recreation, an amount equal to the costs of recreational facilities recommended by the National Park Service; for fish and wildlife, the increased value of annual yields estimated by the Fish and Wildlife Service; and other directly beneficial effects.

Indirect benefits are those derived from the secondary use of project products. Illustrative are the benefits derived from increased economic activity in the trading area and a share of the profits in transporting, processing and distributing increased products from the irrigated farms.

Public benefits are benefits derived from irrigation and comprise the increase or improvement in settlement, the increase or improvement in employment and investment opportunities, the increase or improvement in community facilities and services, and the stabilization of the local and regional economy.

Intangible benefits are those benefits which are not included in the preceding categories but are significant and are described in qualitative terms.

The Corps of Engineers of the Department of the Army recognizes both the tangible and intangible effects of their proposed projects. These effects are as follows:

Direct benefits include, for flood control, (1) the reduction in damages to land and other property measured by the cost of restoration or by the decreased value of the property, (2) the reduction in damage to agricultural crops measured by the market value of crops lost adjusted for any production costs not incurred and replanting possibilities, (3) the reduction of damage due to interruption of business, industry, and commerce, measured by the net loss of income or added costs of operation to the extent that such losses or costs cannot be avoided, and (4) the increase in earnings expected under average future conditions due to changes in use of the land and of other property made practicable by the project; for navigation, savings to shippers and estimated recreational value of harbors and waterways; for power, the estimated actual cost of equivalent power from the most likely alternative source or the estimated value of power to users; and for irrigation, the increase in net farm income.

Intangible benefits include the prevention of loss of life from floods and are described in qualitative terms.

The Department of Agriculture recognizes direct benefits primarily in the economic evaluation of watershed treatment projects. These benefits are described as follows:[6]

6. USDA—Interim Watershed Protection Handbook, April 1955.

Direct benefits consist of increases in monetary yields or annual income in two categories, (1) effects which accrue to immediate local beneficiaries, and (2) effects which accrue to other beneficiaries and the Federal Government.

The Federal Power Commission recognizes direct benefits primarily for its projects. These benefits are evaluated as follows:

Direct benefits are measured for power as the estimated actual cost of equivalent power from the most likely alternative source, or the estimated value of power to users; and for other functions estimates are obtained from the agencies responsible for those functions.

In the measurement of direct and indirect benefits, the several Federal agencies have established and adopted for use certain basic standards which pertain to items such as viewpoint, terms of expression, price levels, time basis, period of analysis, and interest rates. In regard to viewpoint, the identification of tangible benefits consists of determining changes in the supply of goods and services as a result of project construction and operation. Measurement of such benefits consists of determining the difference in the value of the supply of goods and services under estimated future conditions with and without the project. These estimates are based on the assumption that future conditions will be characterized by an expanding economy in which increasing amounts of goods and services will be required to meet the increasing needs resulting from population growth and an upward trend in levels of living. The estimates also represent full coverage of benefits from a public or national viewpoint.

As to terms of expression, project effects composed of increases in available goods and services are converted to and expressed in monetary terms by use of market prices or assigned dollar values expected to prevail at the time when the benefits accrue.

As to price levels, projections of average long-term prices are used as the basis for expressing benefits. National price projections prepared by the Subcommittee on Benefits and Costs have been adopted and are used by the several Federal agencies for economic evaluations. National long-term agricultural price indexes averaging 215 for prices received by farmers and 215 for prices paid by farmers, assuming the index of average prices for 1910-1914 as 100, are used as the basis for agricultural price projections. Prices current at the time of analysis are used in the determination of alternate costs for power, which in turn is used as a measure of power benefits.

Although benefits and costs can be compared on the basis of present values, the usual procedure is to compare average annual equivalent values. Benefits and costs accruing annually, periodically, or in a lump sum are converted to a common time base, which is usually the period of analysis beginning at the estimated date of initial operations of the project. The maximum period is the expected economic life of the project. In the case of the Bureau of Reclamation and the Department of Agriculture, this is 100 years from the date of initial operation of the first unit, or the life of the project, whichever is less. For the Corps of Engineers and Federal Power Commission the economical useful life is limited to a maximum of 50 years.

Interest rates used for the conversion of nonuniform benefits to an equivalent average annual benefit are 2-1/2 percent in the case of the Bureau of

Reclamation, 4 to 5 percent for the Corps of Engineers, 2-1/2 percent for the Department of Agriculture, and none for the Federal Power Commission because power benefits are usually measured directly on an average annual basis and no conversion is involved.

Comparison of the practices pursued by the four principal Federal agencies in determining benefits of water development projects, reveals lack of uniformity in the handling of certain of the items. Probably the greatest differences occur in: (1) the assumption made in regard to the life of the principal project works, and (2) the recognition or nonrecognition of indirect or secondary benefits. In regard to the first item, the Federal Power Commission and the Corps of Engineers assume a useful life of 50 years, whereas the Bureau of Reclamation and the Department of Agriculture assume a life of 100 years or the life of the principal project works, whichever is shorter. The merits of a 50-year period in representing a conservative limit on which to base the investment of Federal funds for some water development projects are recognized. For irrigation projects, however, the scale of development would be limited below that considered desirable from a comprehensive public viewpoint and would be contrary to the true life of the works involved. From an irrigation farmer's viewpoint, the life of the irrigation facilities must be materially in excess of 50 years to be feasible or justifiable. The acquirement and development of a family-type irrigated farm generally represents a lifetime of work and savings for the farmer and would have little or no value if the water supply failed at the end of 50 years. This concept is considered contrary to the objective of Reclamation Law, which is to provide permanent settlement opportunities to farm families and provide the irrigation farmer with the opportunity of getting ahead. Furthermore, where reservoir storage capacity is involved, construction of a project with a 50-year life might preclude subsequent development of a second 50-year project, thus deviating from the objective of making maximum use of a reservoir site or other natural resource, compared with the money invested.

With respect to the second point of divergence in practices, the use by the Department of the Interior and the Bureau of Reclamation of indirect and public irrigation benefits in benefit-cost analyses has been somewhat controversial. Generally, there is agreement that indirect values are created by the projects. The principal point of difference in views, however, is how such values are properly measured and the extent to which they should be used in a comparison of monetary benefits with costs. The procedure proposed by the Subcommittee on Benefits and Costs for measurement of irrigation benefits along theoretical lines would exclude indirect benefits from the economic analysis.[7] This approach assumes a viewpoint which would require the deduction from project benefits of benefits foregone from alternative opportunities. That indirect benefits from resource developments are properly expressed by deducting for alternative opportunities foregone is questioned by the Bureau of Reclamation. The deduction of possible alternative benefits is argued by Reclamation to be equivalent to netting benefits already expressed as a net quantity. Reclamation also takes the position that the project cost adequately reflects the foregoing of alternative opportunities and for that reason there is in effect a double accounting of costs. The exclusion of indirect benefits, also, disregards the regional or area benefits which are paramount to western development.

7. Proposed Practices for Economic Analysis of River Basin Projects, May 1950.

The general objectives of the report of the Subcommittee on Benefits and Costs and of the Bureau of the Budget Circular No. A-47, are to encourage the adoption by the several Federal agencies of more uniform policies, standards and practices for the evaluation of proposed water development projects. This certainly is a sound objective and much has been accomplished in this direction. To invoke, however, a purely theoretical procedure which fails to consider the functional purposes of agency programs or the purposes of projects to meet area and regional needs is unsound. This point was duly recognized and well expressed in a statement by the Director of the Bureau of the Budget in his letter on the Colorado River Storage Project which reads as follows:

> "It is recognized that a basic purpose of the reclamation laws is to spur development in the West. Consequently, it follows that the justification of a reclamation project is not adequately measured by a simple comparison of project costs with the dollar value of the agricultural produce and other goods and services produced by the project."

Director Hughes also made this significant comment on Budget Circular No. A-47, in his appearance before the House Committee on Interior and Insular Affairs:

> "We realize, of course, that the most the final document can do is to provide the guidelines and standards which are absolutely necessary for making better decisions in the difficult process of selecting projects to be recommended for authorization. No one could hope to be wise and informed enough to devise a fixed formula that would always give the answer under every circumstance."

A desirable water development project is designed to optimum size and scope, it is designed to meet specific needs and to solve specific problems, it is designed to improve the use of natural resources, and it is designed to produce beneficial effects in excess of its costs. All of these objectives involve consideration of indirect benefits. The opportunity for water development projects rests upon the fact that certain resources today are unused, partly used, wrongly used, or inefficiently used. This maladjustment creates needs and problems which establish guides for project design. The needs and problems also may be compared with project accomplishments. Direct effects do not adequately measure the extent to which sound economic development in the area of study will be promoted, and indirect effects are necessary to determine the relationships of the project area to a general scheme of basin development. Project analysis without recognition of indirect benefits is only a partial analysis which distorts evaluation of the project in relation to its objectives. These objectives may recognize economic characteristics which show the study area to be an economically depressed area, an area of resource depletion and economic decline, an area of unbalanced development, an area in need of stabilization, an area with a potential for economic growth or agricultural settlement, or an area of important conservation and cultural values. These particular types of problems are not susceptible of informative analysis in terms of direct monetary benefits alone. The full meaning of these characteristics would be obscured by a uniform framework of analysis which does not recognize the ways in which one area differs from another. Just as it is inconsistent to design the reservoir capacity of a project for permanent irrigation settlement for only 50 years of useful life, so also is it

shortsighted to attempt to meet the needs and problems of an area without full coverage of project effects. The strengthening of problem areas is a means of strengthening the regional and national economy, and analysis of these problems requires analysis from a regional or area viewpoint as well as from a national viewpoint.

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Note: Paper 982 is part of the copyrighted Journal of the Irrigation and Drainage Division of the American Society of Civil Engineers, Vol. 82, No. IR 2, May, 1956.

Discussion of
"RIVERBED DEGRADATION BELOW LARGE CAPACITY RESERVOIRS"

by M. Gamal Mostafa
(Proc. Paper 788)

M. L ALBERTSON,* M. ASCE and H. K. LIU**.—The subject of riberbed degradation downstream from reservoirs is one with which engineers throughout the world will be concerned increasingly as more and more flow-regulating structures are built. Therefore, the author is to be thanked for presenting to the profession the results of his study on this timely subject.

Logic and observation in the field and in the laboratory have shown that scour and degradation will occur in any alluvial channel if the flow is not saturated with bed material. Therefore, for a given discharge and channel width, scour will occur until equilibrium is reached either by increasing the resistance of the bed to scour (i.e., increasing the size of the exposed bed material), or by decreasing the carrying capacity (i.e., decreasing the slope), or by a combination of both of these. In either case degradation occurs until a stable channel is reached.

In the first case the development of a stable channel is dependent upon the availability of coarse material in the bed, so that as selective sorting takes place the bed gradually becomes covered or plated with coarser material which can withstand the forces of scour. The necessary size of this material can be determined to some extent by the use of the stable channel theories of Lane(1) and Blench.(2)

On the one hand, if the necessary size of coarse material is readily available in the bed, the amount of degradation will be small and equilibrium will be reached quickly. On the other hand, if coarse material of the necessary size is not available in the bed, then degradation must continue until the slope is decreased to the point where the channel is stable for the coarser fractions of bed material. This ultimate slope also can be predicted by use of the stable channel theories.

In view of the foregoing comments, it is quite possible that the application of the stable channel theories to the problem of riverbed degradation would be helpful.

The writers would like to point out that, in a given alluvial channel having steady, uniform flow, the various dependent variables DV are functions of certain independent variables as follows:

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1. Lane, E. W., "Design of Stable Channels," Trans. ASCE, Vol. 120 (1955), pp 1234-1279.
2. Blench, T., "Regime Theory for Self-formed Sediment-bearing Channels," Trans. ASCE, Vol. 117, (1952), pp 383-408.

$$DV = \phi \left[\text{discharge, slope, } \begin{matrix} \text{characteristics} \\ \text{of the water} \end{matrix} , \begin{matrix} \text{characteristics} \\ \text{of the bed and} \\ \text{bank materials} \end{matrix} \right] \quad \text{(a)}$$

The dependent variables include such factors as the Chezy resistance coefficient, the concentration and distribution of the total load and the suspended load of sediment, the shape of the channel cross section, and the depth of flow.

In most developments of Eq (a) for turbulent flow by either analytical methods or by dimensional analysis, or by a combination of both, the velocity of flow is found to vary with the square root of the slope. This is contrary to Eq 5 by the author. Therefore, the writers would like to suggest that consideration be given to the following equation which follows from Eq (a):

$$C/\sqrt{g} = \phi\,(Re,\ d/R) \quad \text{(b)}$$

wherein C is the Chezy resistance coefficient $C/\sqrt{g} = \frac{u}{\sqrt{gHS}}$, Re is the Reynolds number $Re = \frac{uR}{\nu}$, d is the characteristic size of the bed material, u is the mean velocity, R is the hydraulic radius, and ν is the kinematic viscosity of the water. The writers have found a significant correlation between Eq (b) and the data available from both laboratory and field experiments. Furthermore, these data show very clearly that beyond a certain value of Re the roughness decreases and the concentration increases with increasing Re.[3,4] This conclusion is in accordance with the author's comment. However, the results of the writers show that for certain ranges of Reynolds numbers and relative roughness the opposite effect is also found.

Since the process of degradation is from upstream (starting at the toe of the dam) to downstream, it seems logical to begin the computation of degradation by the successive increament method at the toe of the dam, rather than some distance downstream such as a_1 in Fig. 3.

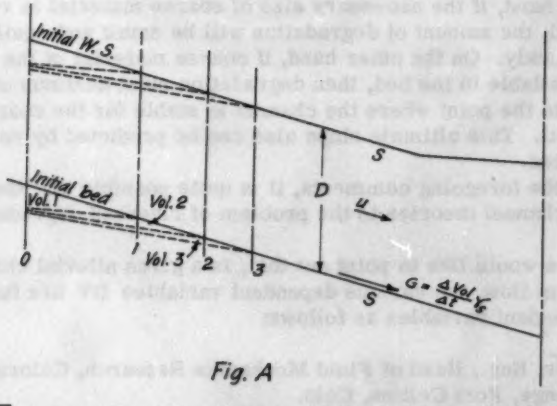

Fig. A

3. Ali, S., "Some Aspects of Roughness of Alluvial Channels," M. S. Thesis, Aug. 1953, Colorado A and M College, Fort Collins, Colo.
4. Albertson, M. L. "Roughness in Alluvial Channels," Research Report, Civil Engineering Dept., Colorado A and M College, Fort Collins, Colo. 1953.

For a given discharge, slope of stream, size of sediment, and temperature of water, the stream has a certain capacity to carry sediment. If such a capacity is reached by eroding upstream reaches, the downstream bed will be unaffected initially. However, once the bed within a reach is eroded, see 0-1 in Fig. A for example, the slope will decrease, the capacity of erosion will decrease, and the erosion process will shift downstream to pick up more sediment in order to satisfy the capacity of the stream. The rate of erosion between Section 1 and 2 in the second time interval will not be as high as the first time interval between Section 0 and 1. However, the total sediment volume Vol_2 will be the same as Vol_1 (assuming no change in the composition of the sediment).

In order to estimate the rate of degradation more accurately, it is necessary to study the mechanics of degradation more thoroughly. Since the phenomenon of degradation is a condition of non-equilibrium and unsteady flow, the present knowledge of the mechanics of sediment transport is much too limited to enable accurate solution of the problem. The ideas presented in the paper and in this discussion are over-simplified as far as degradation in a natural stream is concerned. Nonetheless, it is only through a simplified beginning that a more exact (and perhaps more complex) solution may eventually be found.

PAPERS AND INDEX PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW) divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 66 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 861 is identified as 861 (SM1) which indicates that the paper is contained in Issue 1 of the Journal of the Soil Mechanics and Foundations Division.

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c. Discussion of several papers, grouped by Divisions.

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